STUDY ON PROBABLE RADIONUCLIDE CONTENTS AND THEIR DOSE ASSESSMENT IN SAND, SOIL AND WATER SAMPLES COLLECTED FROM THE RUPSHA RIVER, KHULNA

M. Sc. Thesis

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DEPARTMENT OF PHYSICS
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DECLARATION

This is to certify that the thesis work entitled “Study on Probable Radionuclide Contents and Their Dose Assessment in Sand, Soil and Water Samples collected from the Rupsha River, Khulna” has been carried out by Tuhina Islam in the department of Physics, Khulna University of Engineering & Technology, Khulna, Bangladesh. The above thesis work or any part of this work has not been submitted anywhere for the award of any degree or diploma.

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Approval

This is to certify that the thesis work submitted by Tuhina Islam entitled “Study on Probable Radionuclide Contents and Their Dose Assessment in Sand, Soil and Water Samples collected from the Rupsha River, Khulna” has been approved by the board of examiners for the partial fulfillment of the requirements for the degree of M. Sc. in the Department of Physics, Khulna University of Engineering & Technology, Khulna, Bangladesh in April 2016.

BOARD OF EXAMINERS

DEDICATED
TO
MY BELOVED PARENTS
&
RESPECTED TEACHERS

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ABSTRACT

The radionuclide contents and their activity concentrations in soil, sediment and water samples collected from in and around of Rupsha River, Khulna, Bangladesh have been determined by using a High Resolution Germanium detector (HPGe) of 20% relative efficiency. A total of 44 samples of three categories were collected and analyzed. The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the soil samples of the Rupsha River side area have been found to be varied from 42.99 ± 8.60 to 53.92 ± 7.86 BqKg^{-1}, 64.90 ± 6.60 to 94.16 ± 6.74 BqKg^{-1} and 581.02 ± 77.66 to 1098.50 ± 124.90 BqKg^{-1} respectively with an average value of 50.16 ± 7.20 BqKg^{-1}, 77.23 ±7.43 BqKg^{-1} and 864.63 ± 101.69 BqKg^{-1} respectively. For sediment samples the activity concentrations of the corresponding radionuclides ranged between 40.86 ± 4.31 to 58.27 ± 5.23 BqKg^{-1}, 57.60 ± 6.84 to 82.78 ± 7.50 BqKg^{-1}, 578.39 ± 74.62 to 1038.69 ± 110.70 BqKg^{-1} respectively with an average value of 50.46 ± 6.20 Bq/Kg, 73.99 ± 7.56 BqKg^{-1}and 881.49 ± 100.25 BqKg^{-1} respectively. The results for both the soil and sediment samples obtained for the corresponding nuclides are slightly higher than the worldwide average values of 35, 30 and 400 BqKg^{-1}. The activity contents of the water samples did not show any evidence of enhancement. The calculated average absorbed dose rates due to these radionuclides in soil and sediment samples have been found as 106.13 nGyh^{-1} and 105.03 nGyh^{-1}, respectively which is higher than worldwide average values. The estimated outdoor annual effective dose ranged from 0.11 to 0.14 mSvy^{-1} and 0.10 to 0.14 mSvy^{-1} with the mean values of 0.13 mSvy^{-1} and 0.13 mSvy^{-1} for soil and sediment samples, respectively. The values of radium equivalent activity in almost all the samples were less than 370 BqKg^{-1}. On the other hand, the values of external hazard index for soil and sediment samples varied between 0.52 to 0.67 and 0.49 to 0.67 with the average values of 0.61 and 0.61, respectively. The values are less than unity in all the samples that indicate the non-hazardous nature of the samples and there is no possibility of immediate health effect on the workers, public and environment.

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ABBREVIATION

BAEC	Bangladesh Atomic Energy Commission
ICRP	International Commission on Radiological Protection
QF	Quality Factor
IAEA	International Atomic Energy Agency
WHO	World Health Organization
HPGe	High Purity Germanium Detector
ICRU	International Commission on Radiological Units
PP	Pair Production
INST	Institute of Nuclear Science and Technology
HPS	Health Physics Society
LLD	Lower Limit of Detection

CHAPTER I

Introduction

1.1 General Introduction

Radioactivity and radiation are part of the earth’s natural environment. At the very beginning when there were no sign of lives in the universe, still was full of radiation (Kannan *et al*., 2002). All the constituents of our environment such as soil, water, air and many other constructing materials e.g. brick, cement, wood etc. contain varying amount of radioactivity. Studies on radiation levels and radionuclide distribution in the environment provide vital radiological baseline information. Such information is essential in understanding human exposure from different sources of radiation.

The applications of radiation have become part and parcel in human life. We receive radiation emitted from the floor and walls of our homes, food we eat and drink, and the air we breadth. The concept of technologically enhanced natural radioactivity was introduced in the mid-seventies. It represents the unintentional exposure to natural sources of radiation which would not exist without the technological activity (UNSCEAR, 2000). Main sources of radiation are: (a) Radioactive substance in the earth crust (b) Cosmic rays from outer space which bombard the earth (c) Cosmogenic radionuclides produced by cosmic ray interactions (d) Trace amounts of radioactivity in the body (e) Human produced radionuclides.

Radionuclides become a part of the soil in three ways: (i) as part of Earth’s original crust (primordial radionuclides) (ii) produced and deposited by cosmic ray interactions (cosmogenic radionuclides) and (iii) through man-made releases (man-made radionuclides and activities). Natural radioactivity is widespread in the earth environment and it exists in various geological formations such as earth crust, rocks, soils, plants, water and air. The total background radiation in the earth’s environment is due to the contributions from natural (cosmic and terrestrial) as well as artificial (fall-out from nuclear weapon test, nuclear accidents, discharge from nuclear reactors etc.) radiation sources. Soil provides a direct source of radioactivity in food chain due to its uptake by agricultural plants. The radioactivity caused by radionuclides can transfer from soil, water and air to plants, trees and other biological elements and finally to human body. The natural radioactivity in the environment is the main source of radiation exposure for human body. Natural radionuclide in soil, sediment and water contribute a significant amount of background radiation exposure to the population through inhalation and ingestion as well as through direct external exposure.

The main contributor radionuclides responsible for human exposure are ^{226}Ra, ^{232}Th and ^{40}K and these radionuclides in the solid and liquid samples are not uniformly distributed and vary from region to region (Miah *et al*., 2012). Therefore, the knowledge of their distribution in soil, sediment and water play an important role in radiation protection activities (Rani and Singh, 2005; Kannan *et al*., 2002). The radioactivity concentration of these nuclides above permissible level is very harmful to the human body. Therefore, measurement of natural radioactivity in these elements and the radiation doses arising from these radionuclides are of great interest to the researchers which have led the nationwide surveys throughout the world (Asimov, 1957; Zhang, 2012). Soil contains natural radionuclides of wide range of activity levels. This radioactivity can be transported to the earth surface by several processes including tectonic movement, volcanic activity, ground water flow etc. The transportation by groundwater flow and similar mechanism depends on the solubility and chemical reactions of the radioactive substance and the porosity of the ground (Tchokosssa *et al*., 2012).

Bangladesh is an agricultural dependent country. Soil, sediment and water are main vital elements for agriculture. Rupsha is one of the zones for agriculture located at Khulna city of Khulna division which agriculture are mainly dependent on our area of interest that is Rupsha river. Industrial activities discharge untreated or poorly treated industrial wastewater, effluent and even sludge into the surrounding environment which may contain elevated level of radioactivity. Besides, the farmers in that area are randomly using fertilizers and pesticides in agricultural lands out of their ignorance. Apparently, a very little work has been done and almost no significant data are available on the radioactivity contents in the soil, sediment and water of Rupsha River. Moreover, probable radiological impact on the people and environment due to the radioactivity content in these environmental elements needs to be determined for the radiation protection purpose.

The purpose of this study was to evaluate the radioactivity concentration of soil, sediment and water samples collected from in and around of Rupsha river in Khulna district of Bangladesh and to estimate health effect due to the activity of those radionuclides. The data generated in this study may contribute to determine the baseline database of natural radioactivity in soil, sediment and water sample in the development of future guidelines in the country for radiological protection of the population. The results of this study can provide valuable information for risk assessment of the utilization of soil, sediment and water in the region of Rupsha River, Khulna, Bangladesh.

1.2 Radiation

Radiation is a form of energy which may exist as an electromagnetic wave or quanta. Travelling through space, it can transmit all or part of its energy on contact to matter. Radiation of special interest includes electrons, heavy charged particles, photons and neutrons. Each of the particles tends to loss energy by interaction with the electrons and nuclei of matter and each produces ionization in different degrees (Eisenbud, 1973).

Ionizing and Non-ionizing Radiation

Radiation is broadly classified into two groups. They are Ionizing Radiation and Non-ionizing Radiation. Ionizing radiation is defined as any particle or ray with sufficient energy removing electron from atoms or molecules (IAEA, Module1.4) i.e. when a radiation possesses sufficient energy to ionize a neutral atom, the radiation is said to be ionizing radiation. It has such a high energy that it alters an atom or a molecule permanently. It may consist of a stream of high energy particles e.g. electrons, photons, alpha particles or short wavelength electromagnetic radiation e.g. X-ray, gamma ray (Dictionary of Physics, 2009-10). The ionization energy of an atom and the threshold energy for ionization are different for different atoms as the threshold energy depends on the nature of the atom. In biological concern, the effect of ionizing radiation can be very harmful. Ionizing radiation is much more effective and dangerous for living beings than non-ionizing radiation. Clearly the radiation with energy less than the threshold energy is known to be non-ionizing radiation like ultraviolet, visible light, infrared, microwaves and radio waves. Non-ionizing radiation can alter atoms or molecules only for a very short time (Amon and Oberhummer, 2004).

Classification of Ionizing Radiation

When a radiation possesses sufficient energy to ionize a neutral atom, the radiation is said to be ionizing radiation. The ionization energy of an atom and the threshold energy for ionization are different atoms and the threshold energy depends on the nature of the atom. Clearly the radiation with energy less than the threshold energy is known to be non-ionizing radiation. Ionizing radiation is very harmful for biological cells. In radioactive phenomenon, nuclear radiation occurs as a result of spontaneous disintegration of atomic nuclei. These nuclear changes can give rise to several types of radiation such as- (a) α- radiation, (b) βradiation and (c) γ- radiation. γ-rays either from isomeric transitions or more commonly an excess energy following particle emission and interaction conversion of electrons, resulting from electromagnetic interaction between the nucleus and orbital electrons

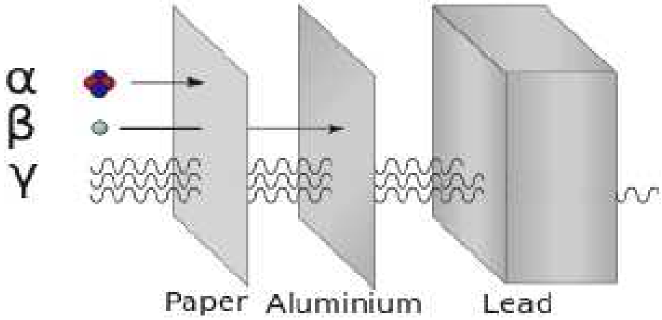

Fig 1.1: Alpha, Beta and Gamma radiation penetration

(a) Alpha Radiation

Alpha radiation is a coulomb repulsion effect and also a nuclear phenomenon. Alpha radiation consists of a stream of positively charged particles, called alpha particles, which have an atomic mass of 4 and a charge of +2 (a helium nucleus). When an alpha particle is ejected from a nucleus, the mass number of the nucleus decreases by four units and the atomic number decreases by two units. For example (Hendry *et al.*, 2009)

$$^{238}U_{92} \rightarrow {}^{4}He_{2} + {}^{234}Th_{90}$$

Thus an alpha particle is a highly energetic helium nucleus that emitted from the nucleus of the radioactive isotope when the neutron- to-proton ratio is too low. The nuclei, which contain 210 or more nucleons, are so large that the short-range nuclear forces that forces that hold then together are barely able to counter balance the mutual repulsion of their protons. Alpha decay occurs in such nuclei as a means of increasing their stability by reducing their size. Alpha particles are mono-energetic and energy lies between 4 - 9 MeV.

(b) Beta Radiation

Beta radiation is a stream of electrons, called beta particles. When a beta particle is ejected, a neutron in the nucleus is converted to a proton, so the mass number of the nucleus is unchanged, but the atomic number increases by one unit. For example (Hendry *et al.*, 2009):

$$^{234}Sr_{90} \rightarrow {}^{0}e_{-1} + {}^{234}Pa_{91}$$

They are emitted in radioactive decay with various energies ranging from nearly zero to a maximum energy characteristic of the decaying radioactive isotope. The beta rays can travel a few feet in air but cannot penetrate much beyond the depth of the skin of a person. Hence, like the α-rays, they are harmful only when they are inside the body. From outside they can cause only skin burns. Because of the lower mass of β- particles, than α-particles, β-particles (β^- & β^+) are more penetrating than α-particles.

(c) Gamma Radiation

Gamma radiation is only type of electromagnetic radiations, similar to light but of much higher energy. The wavelength of gamma rays is much shorter than that of visible light. the energy of electromagnetic radiation or photon is given by $E = h\nu$, where h is the Planks' constant (6.63×10^{-34} J-sec), ν is the frequency equal to C/λ, C being the velocity of light (3×10^{8} m/sec) and λ is the wavelength of the radiation. Gamma rays are emitted in radioactive decay along with alpha or beta radiations. Gamma rays have discrete energies like alpha rays.

1.3 Radioactivity

Radioactivity may be defined as spontaneous nuclear transformations that result in the formation of new elements (Cember, 1989), discovered by A. H. Becquerel. Radioactivity is the term used to describe those spontaneous, energy-emitting, atomic transitions that involve changes in state of the nuclei of atoms. The energy released in such transformations is emitted in the form of electromagnetic or corpuscular radiations. In more specific words, it is found that a few naturally occurring substances consist of atoms which are unstable that is, they undergo spontaneous transformation into more stable product atoms (Martin and Harbison, 1979). Such substances are said to be radioactive, the transformation is called radioactivity and the transformation process is termed as radioactive decay. Radioactive decay is usually accomplished by the emission of charged particles and gamma rays. All chemical elements may be rendered as radioactive by adding or subtracting (except for hydrogen and helium) neutrons from the nucleus of the stable ones (Bhuiyan, 2009). Studies of the radioactive decays of new isotopes far from the stable ones in nature continue as a major frontier in nuclear research. The availability of this variety of radioactive isotopes has stimulated their use in a wide range of fields including chemistry, biology, medicine, industry, and artifact dating, agriculture and space exploration.

The Discovery of Radioactivity: Early Concept

In 1896, A. H. Becquerel, the father of radioactivity, was investigating the fluorescence of sulphate, uranium and potassium using a photographic plate. He found that the plate was affected by certain radiations, irrespective of whether or not the salt was caused to fluorescence. And thus, Becquerel gave the concept of radioactivity. After that, Marie Curie investigated this property in a number of minerals containing which she found more active than uranium itself, and first coined the word radioactivity. In 1898, she and Pierre Curie discovered Polonium and Radium in collaboration with G. Belmont. Later E. Rutherford showed that two types of radiation were emitted by uranium, namely the alpha rays that were completely stopped by a thin sheet of paper and the beta rays that were much more penetrating than alpha rays. In 1990, P. Villard discovered gamma rays, even more penetrating radiations. Subsequently, the alpha and beta rays were shown to be ionized helium-4 atoms and electrons respectively, and the gamma rays to be electromagnetic in nature i.e. energetic photon (NCR, 1994). Several decades later at 1934, Irene and Frederic Joliot Curie discovered man-made radioactivity

Radioactive Transformation Mechanisms

The mechanism of radioactive transformation can be described by the following points.

(1) Radioactive transformations are accomplished by one of several mechanisms e.g. alpha particle emission, beta particle emission, positron emission and orbital electron capture

(2) Each of these transformations or reactions may or may not be accompanied by gamma radiation.

(3) Radioactivity and radioactive properties of radionuclides are determined by nuclear considerations only (e.g. no. of neutrons, no. of protons, excited energy in the nucleus etc.) and are independent of chemical and physical states of the radioisotopes.

(4) The exact mode of radioactive transformation depends on two factors.
They are as follows:

(a) The particular type of nuclear instability that is whether the neutron to proton ratio is either too high or too low in the nucleus.

(b) The mass energy relationship among the parent nucleus, daughter nucleus and the emitted particle.

Classification of Radioactivity

Generally there are two basic classes of radioactivity according to origin. They are:

i. Natural Radioactivity and
ii. Artificial or Induced Radioactivity.

Natural Radioactivity

Natural radioactivity is the result of the spontaneous disintegration of naturally occurring radioisotopes. It originates from extraterrestrial sources as well as from radioactive elements in the earth's crust. It contributes about 90% of the total radiation (Quindos *et al.*, 1992; Eisenbud, 1987). Besides, natural radioactivity includes radiations from naturally occurring radioactive elements which arises from the sources external to the body and from the internal radioactive materials contained in the human body itself. A number of radionuclides occurring naturally are primordial that is, associated with the formation of the earth. A much large number of radioactive isotopes that now exist were produced when the universe was first formed around seven billion years ago. But most of them have decayed out of existence. The radionuclides which now exist are those that have half-life at least comparable to the age of the universe. Radioisotopes with half-life less than about 10^8 years have become undetectable whereas radionuclides with half-lives greater than 10^{10} years have decayed very little to the present time (Bhuiyan, 2009). In most cases, the natural radioactivity on earth varies only within relatively narrow limits. But in some localities, there are wide deviations from normal levels owing to the presence of abnormally high concentrations of radioactive minerals in the local soil and water. The external sources of radiation are cosmic rays, ground and the normal building materials while the internal sources are potassium and radium.

Origin of natural radionuclide

Most of the naturally occurring radionuclides are components of three chains of radioactive elements.

(1) The uranium series originating with ^{238}U.
(2) The thorium series originating with ^{232}Th.
(3) The actinium series originating with ^{235}U.

Elements of uranium, thorium and actinium series and their daughter products contribute major portion of the natural radioactivity (Eric, 1965). In addition, there are singly occurring radionuclides of both cosmic (^{14}C, ^{22}Na etc.) and terrestrial (^{40}K, ^{87}Rb etc.) origin which are also radioactive and do not belong to any series.

(1) The Uranium Series

The ^{238}U and ^{234}U belong to the uranium series. About 99.3% of naturally occurring uranium is ^{238}U, about 0.7% is ^{235}U and a trace quantity about 0.005% is ^{234}U. The Uranium series whose first member is ^{238}U consists of isotopes whose mass numbers are exactly divisible by 4 and leave a remainder of 2. This series, therefore, is called the 4n+2 series (Kaplan, 1964).

(2) The Thorium Series

^{232}Th is the first member of another long chain of successive radioisotopes, called the thorium series. It is very commonly found in the earth's crust. The thorium content in the earth's crust is approximately three times than that of uranium (Rahman, 1991). The mass numbers of all members of the thorium series are exactly divisible by 4. This series, therefore, is called the 4n series (Cember, 1989).

(3) The Actinium Series

The ^{235}U isotope of uranium is the first member of another series called the Actinium series. Here, the mass numbers of the isotopes are exactly divisible by 4 and leave a remainder of 3. This series, therefore, is called the 4n+3 series (Kaplan, 1964). To see more specific data of the three radioactive series, please follow reference no (Trilinear, 1957).

Origin of Potassium

Potassium has a very simple form of radioactive decay. Only one of the several natural isotopes of potassium e.g. ^{40}K is radioactive and it has a relative isotopic abundance of only 0.0118%. Hence, among the low atomic numbered naturally occurring radioisotopes (^{40}K, ^{87}Rb, ^{138}La etc.), ^{40}K is the most important one from the health physics point of view because of its widespread distribution in the environment. No significant fraction of the potassium isotopes takes place in nature and so the radioactivity of potassium is almost constant under all conditions. It is characterized by a single gamma ray of energy 1.46 MeV. Potassium undergoes 3.3 gamma emissions per second per gram (Clark *et al.*, 1966).

Artificial or Induced Radioactivity

The term artificial or induced radioactivity refers to the way in which the new radionuclides are produced rather than to their decay (Kaplan, 1964). Induced radioactivity occurs when a previously stable material has been made radioactive by exposure to specific radiation. Most radio activities do not induce other material to become radioactive. The phenomenon by which even light elements are made radioactive by artificial or induced methods is called artificial radioactivity.

This artificial radioactivity was discovered by Curie and Joliot in 1934 (wikipedia.org). They observed that when lighter elements such as boron, magnesium and aluminum were bombarded with α-particles, there was a continuous emission of radioactive radiations, even after the α−source had been removed. Their study showed that the radiation was due to the emission of a particle carrying one unit positive charge with mass equal to that of an electron. However, in this type of radioactivity, radioisotopes are produced by bombarding nuclei with nucleon particles in an accelerator or nuclear reactor. A nucleus becomes radioactive when it changes from a stable, unexcited state to an unstable excited condition. By bombarding atoms with charged particles of sufficient energy it is possible to raise the nucleus to a state of instability from which it will decay back to its stable state at a characteristic rate measured by the half-life. There are a few radioisotopes which emit neutrons. Beryllium has the lowest neutron binding energy of all the nuclides and is used as a target with both alpha and gamma radioisotopes.

The exposure for an average person is about 3.6 $mSvyr^{-1}$, 80 percent of which comes from natural sources of radiation, the remaining 20 percent results from exposure to artificial radiation sources. Accelerators, reactors, atomic explosion and man-made radioactive sources are the most important sources of artificial radioactivity. The existing main types of man-made radiation sources are light sources, radio, TV, power supply lines, cellular phone network, nuclear medicine, nuclear power plants, nuclear weapon test, commercial products (e.g. tobacco), fertilizer, luminous watch dials and industrial activities. Most of the man-made sources belong to the medical sector. For average persons who have had no medical x-rays, only 3% of their annual radiation dose comes from artificial sources (UNSCEAR, 2000). Exposures to natural sources of radiation may vary little form year to year and involves the whole population of the world to about the same extent. On the contrary, man-made sources may vary significantly with time and the resulting exposures may differ substantially from one population group to another. Artificial radioactivity is also known as man-made radioactivity.

Some induced radioactivity is produced by background radiation, which is mostly natural. However, since natural radiation is not very intense in most places on Earth, the amount of induced radioactivity in a single location is usually very small. Nevertheless, in nuclear explosions, more than 200 radionuclides are produced with half-lives ranging from less than a second to many years (Balles and Sallow, 1951). In addition, a number of activation products arise from neutron activation of weapon materials and the surrounding atmospheric environment (Strom, 1958) as mentioned earlier. A large number of these radioactive isotopes are used for purposes in different fields such as physical science, agriculture, industry, hydrology and medicine. But nonetheless its far-reaching effect can be and is very dangerous to the population and also to the individual one. The only series containing artificial radioactive nuclides is known as the neptunium series. This fourth family of radioactivity is started with the nuclei ^{214}Pu which has a half-life of only 13.2 years and briefly existed only after its formation (Cember, 1989). The only surviving and also the terminal member of the neptunium family is the stable bismuth, ^{209}Bi. This series has derived its name from the longest lived member of the group, neptunium ^{237}Np with half- life 2.2×10^{6} years. Here, the mass numbers of the isotopes are exactly divisible by 4 and leave a remainder of 1. This series, therefore, is called the 4n+1 series.

The 4n+1 series is also called the missing series. It is generally considered that the earth is about 5×10^{9} years old. According to the scientists, if it is assumed, as is probable, that neptunium was formed at the same time as the earth, then many half-lives have elapsed for this nuclide and the amounts still present would be too minute as to be beyond the possibility of detection (Kaplan, 1964). The absence of a naturally occurring 4n+1 series can therefore be discussed. Even if such a series did exist at one time, its members would long since have decayed to ^{209}Bi.

When a nuclear device is detonated, trans-uranium elements are formed through a complicated series of neutron capture and radioactive decay process. These elements produced by nuclear weapon tests have been distributed throughout the world on a global level. In consequences, the interest of physicists and chemists have been greatly aroused and focused on trans-uranium elements as environmental contamination since their presence at relatively high concentrations would represent potential health problems. The major sources of trans-uranium elements in the environment are stated below (Kim, 1990):

- Global fallout due to atmospheric weapon tests and satellite accidents.
- Local contamination from close-in-fallout from nuclear weapon tests.
- Accidents involving military aircraft and nuclear power plants.
- Disposal of wastes from reprocessing power plants.

1.4 Background Radiation

Background radiation is the ubiquitous ionizing radiation that people on the planet Earth are exposed to, including natural and artificial sources. Background radiation is constantly present in the environment and is emitted from a variety of natural and artificial sources. It is impossible to decide whether the natural background radiation has been harmful or beneficial to the development of the human species (Martin and Harbison, 1979). Man has been exposed to radiation from the environment in which he lives. Because of the cosmic radiation that continuously bombards the earth's atmosphere and the existence of the natural radioactivity in the environment, all radiation detectors record some background signal. The nature of this background varies in accordance with the size and type of the detector and with the shielding around the detector. It is often important enough in routine usage so that the majority of the radiation detectors are provided with some degree of external shielding to effect a reduction in the measured levels. The worldwide average background dose for a human being is about 2.4 mSv per year.

Sources of Background Radiation: Background radiations from random sources can be conveniently grouped into six categories.

- The natural radioactivity of the constituent materials of the detector itself.
- The natural radioactivity of the ancillary equipments supports and shielding placed in the immediate vicinity of the detector.
- Radiations from the activity of the earth's surface (terrestrial radiation), construction materials of the laboratory, or other far-away structures.
- Radioactivity in the air surrounding the detector.
- The primary and secondary components of cosmic radiation.
- Radioactivity in the human body.

In addition to the natural sources of background radiation many artificial sources of radiation have been introduced in the past 80 years. These artificial sources now add a significant contribution to the total radiation exposure of the population (Martin and Harbison, 1979).

Radioactivity of Common Materials

The radioactivity of ordinary construction materials is taken into account due to the low concentrations of naturally radioactive elements which is often contained as an impurity. The most important components are potassium, thorium, uranium and the members of the long decay chains of uranium and thorium.

Radiation from Terrestrial Sources

The terrestrial radionuclides are the non-series single stable nuclei such as ^{40}K, ^{50}V, ^{87}Rb, ^{138}In, ^{139}La, ^{147}Sm, ^{176}Lu and the three radioactive series uranium, thorium and actinium headed by ^{238}U, ^{232}Th and ^{228}Ac respectively. The three naturally occurring radio elements namely potassium (^{40}K), uranium (^{238}U) and thorium (^{232}Th) contribute a major part of population dose. Potassium undergoes a simple form of radioactive decay, the decay of uranium and thorium is complex and proceeds sequentially along a chain of disintegrations (Rahman, 1991).

Airborne Radioactivity

A measurable amount of background can originate with radioactivity carried by the air, either in the form of trace amounts of radioactive gases or dust particles (Knoll, 1989). Radon and Thoron are short-lived gases that originate as daughter products in the decay chains of the uranium and thorium present either in the soil or construction materials of the laboratory. Their concentration in the atmosphere can vary significantly depending on the time of day and meteorological conditions (Okabe *et al.*, 1987). To eliminate the influence of radon on the background, the volume around the detector can be made air-tight and purged with a radon-free gas. Airborne dust can contain radioactivity from soil or radon decay products that can largely be eliminated through effective filtration of the air supply to the counting room.

Cosmic Radiation

A significant component of detector background arises from the secondary radiations produced by cosmic ray interactions in the earth’s atmosphere. Cosmic radiation reaches the earth from interstellar space and from the sun. It is composed of a very wide range of penetrating radiations which undergo many types of reactions with the elements they encounter in the atmosphere. The atmosphere acts as a shield and reduces considerably the amount of cosmic radiation reaching the earth's surface. This filtering action means that the dose rate at sea-level is less than at high altitudes. The average dose rate in the British Isles from cosmic radiation is about 0·5 mSvyr^{-1} (Martin and Harbison, 1979). However, the primary cosmic radiation, which can be either galactic or solar origin, is made up mainly protons, might also be a small number of electrons based upon recent studies, plus some helium nuclei and heavy ions, with extremely high kinetic energies. In their interaction with atmosphere, a large amount of secondary particles is produced with energies that extend into hundreds of MeV range (Knoll, 1989). Some of these radiations reach the earth's surface and can create background pulses in many types of detectors. Besides, these radiations expose to population and environment as well. On the earth itself, the effect of cosmic rays has been mainly detected in interactions with the atmosphere. ^{14}C perhaps is the first such observed nuclei (Islam, 2009). Subsequently, ^{3}H, ^{7}Be, ^{10}Be, ^{22}Na and other nuclides have also been observed.

Radiations inside the Human Body

The human body contains very small quantities of the radioactive isotopes ^{14}C and ^{40}K (Martin and Harbison, 1979). The ^{14}C originates in the atmosphere and results in a dose of 10 μSvyr^{-1} in the soft tissue. ^{40}K is naturally occurring radionuclei and contributes about 0·2 mSvyr^{-1} to the gonads. An average human contains about 30 milligrams of ^{40}K and about 10 nanograms (10^{-8} g) of ^{14}C which has a decay half-life of 5,730 years. Excluding internal contamination by external radioactive material, the largest component of internal radiation exposure from biologically functional components of the human body is from ^{40}K. The decay of about 4,000 nuclei of ^{40}K per second makes potassium the largest source of radiation in terms of number of decaying atoms ^{14}C is present in the human body at a level of 3700 Bq with a biological half-life of 40 days.

A significant contribution to the radioactivity in the body comes from the gaseous decay products of the uranium and thorium radioactive series, namely radon and thoron. These gases diffuse from the rocks and soil and are present in easily measurable concentrations in the atmosphere. They are breathed by men along with their decay products and are also taken up by plants and animals with the result that most foodstuffs contain measurable amounts of natural radioactivity. Of ordinary foods, cereals have a high radioactive content while milk, fruits, vegetables and water have a low content (Martin and Harbison, 1979). Radiation pathway into human body is shown in Fig 1.2.

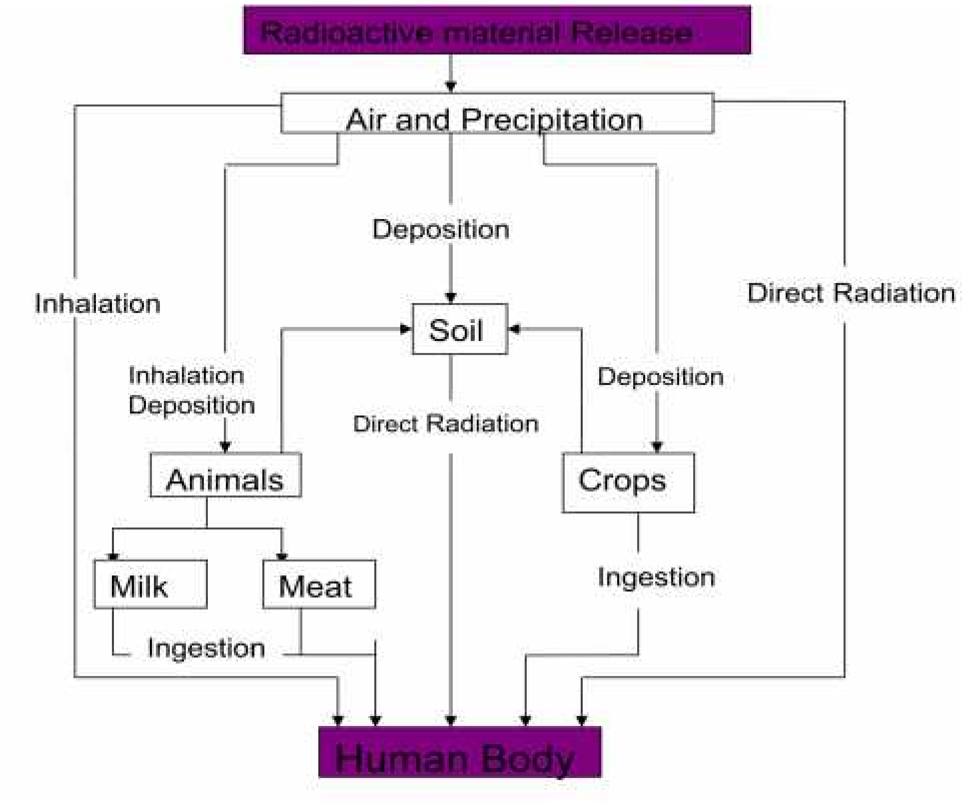

Fig 1.2: Radiation Pathway into human body

From the available information we find that more than half of the average effective dose equivalent is due to radon or the short lived radioactive daughters into which it decays. The total man-made sources contribute less than one-fourth of the naturally occurring background radiation. But this background radiation is not constant everywhere. It varies with location because the amount of radioactive materials is different in soil, water and rock. The increase of cosmic radiation with altitude is also an important fact behind this variation. Among other man-made sources, the largest contribution comes from the diagnostic X-rays. Since the rate of medical practice is different in other paths of the world, the average levels of medical exposure also vary throughout the world. About 80% of radiation dose in human body comes from the background radiation. A calculation shows that 78% of the total exposed radiation on human body originates in nature, 21% in the medical sectors, X-ray machines, accelerators etc., and 1·125% comes from the radiation produced from the nuclear power plants.

1.5 Radioactive Secular Equilibrium

Naturally occurring radioactive nuclides form three series – Uranium, Actinium and Thorium series. In each series, the parent nuclide decays into a daughter nuclide which decays in turn, and so on until a finally stable end product is reached.

Let, N_1 represents the number of atoms of the parent nuclide A at time t. The decay of the parent nuclide can be described by the following equation of decay law,

$$dN_1/dt = -N_1\lambda_1$$

$$\text{or, } dN_1 = -N_1\lambda_1 dt$$

Where, λ_1 is the decay constant.

For the daughter nuclide, $dN_2 = N_1\lambda_1 dt - N_2\lambda_2 dt$

Where, the term $N_1\lambda_1$ represents the rate at which the daughter atoms are formed and $N_2\lambda_2$ represents their rate of transformation.

Upon integration,

$$N' = \lambda_1/(\lambda_2-\lambda_1).N_1[\exp\{-(\lambda_1+\lambda_2)t\}] + N_2[\exp\{-\lambda_2 t\}]$$

Where, N_1 = initial amount of parent present

N_2 = initial amount of daughter present

N'= amount of daughter present after time t

At secular equilibrium,

$\lambda_2 >> \lambda_1$.

Here, the half-life of the parent is very much longer than that of the daughter.

Consequently, we get,

$$\lambda_2 N_2 = \lambda_1 N_1$$

This means that the activity of the daughter is equal to the activity of the parent. When this stage has been reached, the substance is said to be in a state of secular equilibrium and satisfies the following condition.

$$N_1/T_1 = N_2/T_2 = \ldots\ldots\ldots\ldots\ldots = N_{n-1}/T_{n-1} = N_n/T_n$$

Where, $T_1, T_2, \ldots\ldots\ldots\ldots\ldots, T_n$ are half-lives of the respective atoms.

1.6 Radioactive Decay

Radioactive decay is a stochastic (i.e. random) process at the level of single atoms, in that, according to quantum theory, it is impossible to predict when a particular atom will decay (Half Life, 2009). However, the chance that a given atom will decay is constant over time.

For a large number of atoms, the decay rate for the collection is computable from the measured decay constants of the nuclides (or equivalently from the half -lives).

Natural Decay Series: A number of radionuclides occurring naturally are primordial, that is, associated with the formation of earth. Some elements having atomic number of or below that of, lead have one or more radioactive isotopes and all of these may be placed in one or the other radioactive series. Natural radioactivity includes radiations from naturally occurring radioactive elements which arises from the sources external to the body and from the internal radiation materials contained in the human body itself. The external sources of radiation are cosmic rays, the ground and normal materials whilst the internal source of potassium and radium. Soils, rocks contain Uranium and Thorium with their decay products. Elements of uranium, thorium, and actinium series and their daughter products contribute major portion of the natural radioactivity (Clark, 1966).

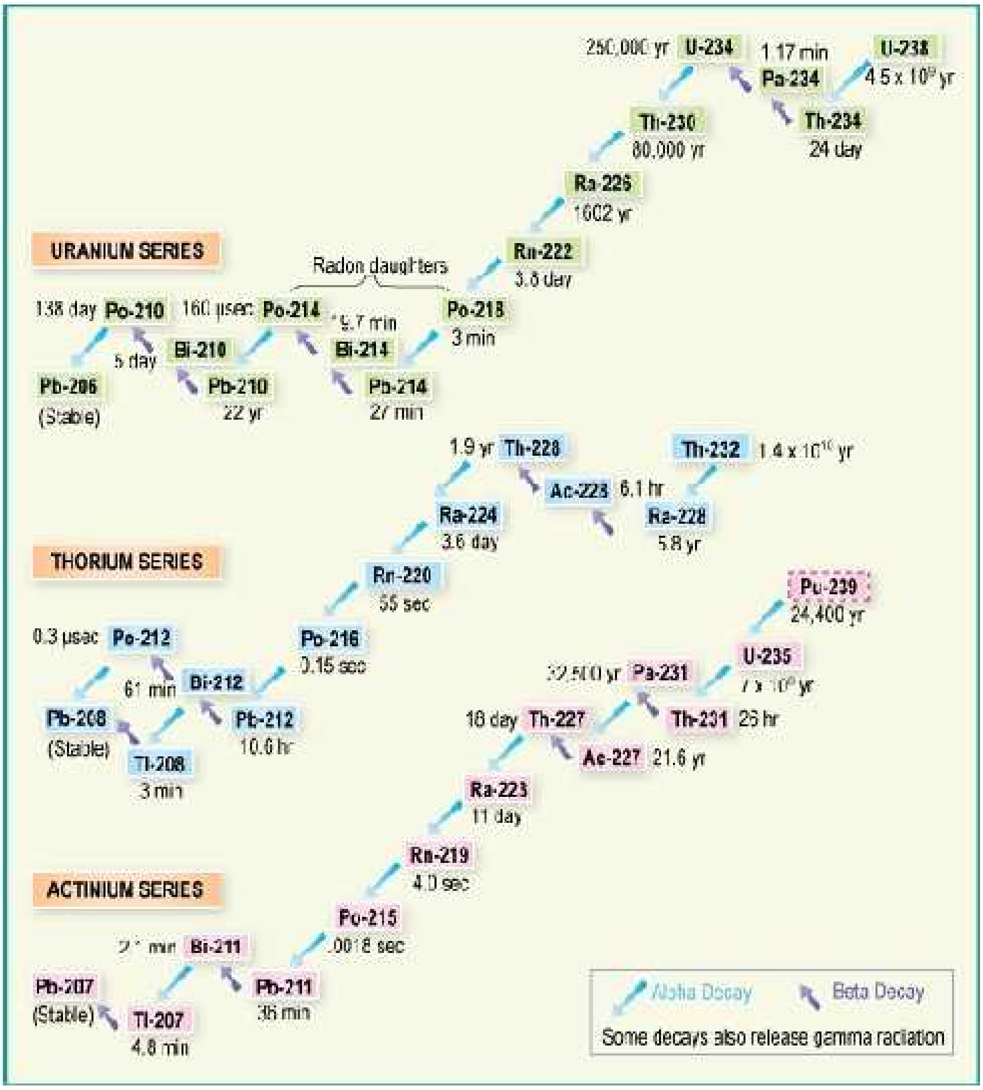

Fig 1.3: Elements of uranium, thorium and actinium series and their daughter products

1.7 Basic Radiation Safety Criteria

As the use of radiation became more widespread and its serious effects recognized, the need of establishing permissible levels of exposure to radiation for workers arose. First in 1925, the International Commission on Radiological Units (ICRU) recommended that the annual permissible dose of radiation should be one-tenth of the erythematic dose – the acute dose that just produce visible reddening of skin. In the mid 1930's the permissible exposure for whole body X-radiation was set at 1 R/week by the NCRP.

After the world- war II, routine operations in the atomic energy industry exposed workers to neutrons as well as radiation from radioactive materials. So one is to work within certain limits of radiation hazard.

For purposes of radiation safety standards the ICRP recognizes three categories of exposure.

Category 1: For occupational exposure, the ICRP recommends the following annual dose equivalent limits (ICRP, 1977).

To prevent	Annual dose equivalent through the whole body	
	All other radiation workers	Pregnant women
Non-stochastic effects (bone marrow damage, gastrointestinal damage etc.)	(a) 0·5 Sv except to the lens of eye. (b) 0·15 Sv to the lens of eye.	(a) 0·15 Sv except to the lens of eye. (b) 0·05 Sv to the lens of eye.
Stochastic effects (cancer, hereditary effect etc.)	0·05 Sv	0·015 Sv

Here, Sv, namely Sievert, is the S.I. unit of dose equivalent.

Category 2: For members of the general public, the ICRP recommends a whole body dose equivalent limit of 5 mSv in a year (ICRP, 1977). On the contrary, the ICRP made no specific recommendations of dose equivalent for a population group.

Category 3: No specific limit was recommended by the ICRP for medical exposure. ICRP recommended that only necessary exposure should be made. These exposures should be justified on the basis of benefits that would not otherwise have been received (ICRP, 1977).

1.8 Motivation of the Present Study

Radionuclides are the sources of radioactivity and emit nuclear radiations which have become a part of our daily lives. The properties of radiations have been widely applied to various purposes such as medicine, biology, industry, agriculture, and electric power generation. As a result of the applications of radiation, humans can be exposed to the radiation emitting from different radioactive sources depending upon their activities and surroundings. Moreover the radionuclides generated during nuclear accidents could be transported into the environment below or above the earth surface. They could mix up with the atmospheric gaseous components and circulated around until they are brought down to the surface of the earth through rains. The mixing up, transport and setting processes are random in their very nature and their distributions too are random. As a result the atmosphere such as soil, water, foodstuff etc are contaminated and the level of contamination varies place to place. It is important to make studies on the distribution of various radionuclides present in the environment and the different factors that cause migration of various radionuclides from soil to food chain and their subsequent transfer to the human body.

The present work aims at determining the concentrations of the natural radionuclides of the uranium and thorium series and of ^{40}K and a fission product of the environmental elements from Rupsha River, Khulna. The concentrations of the radionuclides present in the soil, sediment and water samples are expected to be greatly influenced by the geo-morphological conditions in the area. The present results will be useful for comparing with other previous radioactivity measurements for subsequent measurement establishment of a relation about its impact on the man and the environment of Rupsha in Khulna.

As such this work would be useful as base line data for the planning and for the future work of this area. The accumulation of information on natural and probable artificial radioactivity is of great value for radiation protection. Hence this work is extremely important to carry out approximately designed program for environmental radioactivity and radiation monitoring aimed at minimizing radiation exposure to population.

1.9 Layout of the dissertation

In this paragraph, an overview and a brief idea of the whole thesis paper have been pointed out. As a starting,

- Chapter 1: includes the most general and important concepts about the thesis topics.
- Chapter 2: some important and related previous works, taking place in home and abroad, have been reviewed. It also contains all of the theoretical knowledge and explanations needed to understand the related background of the study and deals with the effective study of radiological impact of radioactivity on human body.
- Chapter 3: describes the sample preparation method, labeling and experimental set up, calibration of the HPGe detector system and calculation methods of the experiment.
- Chapter 4: the data tables and graphical representations, results and discussion are presented.
- Chapter 5: overall conclusion and suggestions for future work is given in.

CHAPTER II

Theoretical Background

2.1 Introduction

To understand the physical basis for radiation and the theory of radiation shielding, health physicist must understand the mechanisms by which the various radiation interact with matter. In most instances, these interactions involve a transfer of energy from the radiation to the matter with which it interacts with matter consists of atomic nuclei and extra-nuclear electrons. The exposure of the human being to radiation is in part external- from the materials around him- but it is also in part internal, by reason of the ingestion of food and water having some radioactive components and the inhalation of radioactive particulates or gases in the atmosphere. Human body possesses no biological sensors for radiation. Consequently, severe damage may be suffered without any realization at the time of irradiation on the part of exposed subject. So man depends on instrumentation for detection and measurement of radiation, for this reason, scientists feels the necessity for the assessment of the radioactive sources in the environment. In the present Study, the natural radioactivity level in the soil, sediment and water samples collected from in and around of Rupsha River have been observed. These environmental elements have been collected to observe and compare the radioactivity in the sample. It will also help to observe the extent of influence of radiation on the environmental elements around. The measurements of radionuclide in environmental elements have been done widely, especially abroad, in several countries, and the results on it have been reported in many journals. A review work on it has been carried out by searching the recent editions of some journals. Some of the important works are summarized below:

2.2 Review of the Previous Work

1. Tchokossa *et al.*, (2012), surveyed radioactivity content and associated radiological risks in various soils used for agriculture and building materials in Cameroon by means of a well-calibrated high purity germanium detector. Soil samples were collected directly from the agricultural farms and the brick’s factories, air-dried at room temperature to a constant mass, crushed, sieved and sealed for at least one month before analysis. The specific activity of ^{228}U ranged from 5.36±0.39 to 51.28±9.67 Bqkg^{-1} with an average of 34.52±7.18 Bqkg^{-1}; ^{232}Th from 4.03 ±1.03 to 24.74±3.10 Bqkg^{-1} with an average of 16.67 ±4.28 Bqkg^{-1}; ^{40}K ranged from 16.18±3.11 to 467.40 ±50.80 Bqkg^{-1} with an average of 186.96±16.21 Bqkg^{-1}; while that of the fallout ^{137}Cs ranged from 0.00 to 4.79±1.75 Bqkg^{-1} with an average of 2.32±0.99 Bqkg^{-1}; The mean result obtained for the representative levels index (I_γ), the radium equivalent (Ra_{eq}), the total absorbed dose rate (ADR), the external hazard index (H_{ex}), the internal hazard index (H_{in}) and the Caesium intervention levels were 0.52, 72.75 Bqkg^{-1}, 33.73 nGyh^{-1}, 0.20 Bqkg^{-1}, 0.29 Bqkg^{-1} and 0.0028 Bqcm^2 respectively. The discrepancies of our data can be attributed to several factors such as past nuclear disasters, geological formation, transport process, etc. Although our results are just some fractions of the international standard limit, but still within the same ranges when compared with those obtained elsewhere. These results also will serve as a baseline data for future investigations.

2. Lu *et al.*, (2012), determined activity concentrations of natural radionuclides ^{226}Ra, ^{232}Th and ^{40}K in soil around Baoji second coal-fired thermal power plant of china using gamma ray spectrometry. The mean activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in soil were found to be 40.3±3.5, 59.6±3.1 and 751.2±12.4 Bqkg^{-1}, respectively which are all higher than the corresponding average values in Shaanxi, Chinese and world soil. The radium equivalent activity Ra_{eq}, the air absorbed dose rate (D), the annual effective dose (E), the external hazard index H_{ex} and internal hazard index H_{in} were evaluated and compared with the internationally reported of reference values. All the soil samples have R_e lower than the limit of 370 BqKg^{-1} and H_{ex} and H_{in} less than unity. The overall mean outdoor terrestrial gamma air absorbed rate is ~86.6±3.4 nGyh^{-1} and the corresponding outdoor annual effective dose is 0.106± 0.004 mSv, which is higher than the worldwide average (0.07mSvY^{-1}) for outdoor's annual effective dose.

3. Zhonghal *et al.*, (2011), measured the activity concentrations of natural and artificial radionuclides in the eastern region of Sichuan province (China). One hundred and ninety-three soil samples from this region were collected and analyzed by high-purity germanium gamma spectrometry. The measured results show that the average radioactivity concentrations of ^{226}Ra, ^{232}Th and ^{40}K and ^{137}Cs in the soil samples are 26, 49, 440 and 6 Bqkg^{-1} respectively. The calculated average radium equivalent activity is 130 Bqkg^{-1}; which is less than the recommended limit of 370 Bqkg^{-1}, the absorbed dose rate and annual effective dose are 60 nGyh^{-1} and 74 μSv, respectively. This is the first time absorbed dose rate in the east region of Sichuan has been mapped. Overall, the environmental radiation background is greater in the Southern part of the area studied than in the Northern.

4. Faanu *et al.,* (2011), The activity concentrations of natural radionuclides ^{226}Ra, ^{232}Th and ^{40}K in soil, rock, waste and tailing samples were measured by gamma spectrometry using high-purity germanium detector. In addition, radiological hazard assessments due to these natural radionuclides were carried out. The average activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K determined were 13.61 ± 5.39 Bq kg^{-1}, 24.22±17.15 Bqkg^{-1} and 162.08 ±63.69 Bqkg^{-1} respectively. The average annual effective dose was 0.17+0.09 mSv. The average radium equivalent activity concentration in the sample was 61.00Bqkg^{-1}. The calculated external and internal hazard indices were less than unity with average values of 0.16 and 0.20, respectively. The result of the ^{226}Ra emanation fraction varied in a range of 0.51–0.80. The results obtained show that soil, rock and waste materials that may be used for construction of buildings may not pose any significant radiological hazards to the inhabitants in the study area.

5. Saat *et al.*, (2011), studied the natural radionuclides (^{226}Ra,^{232}Th and ^{40}K) activity concentrations in soil and the corresponding surface doses at eleven locations around UiTM-Perhilitan Research Station Taman Negara, Pahang were determined to assess the possible radiation hazard to visitors in that area. The gamma activities and the surface doses were determined using high resolution gamma- ray spectrometer and portable radiation survey meter. The mean activity concentrations in the area for ^{226}Ra, ^{232}Th and ^{40}K are 99.13 Bqkg^{-1}, 139.98 Bqkg^{-1} and 598.24 Bqkg^{-1} respectively, while on average the doses are 0.215 μSvhr^{-1} at one meter from ground. The activities were higher than world average and doses were in the ranges, while radiation hazard indices were slightly greater than unity in four locations.

6. Mollah *et al*., (1994), studied the environmental radioactivity in soil samples in Atomic Energy Research Establishment (AERE), savar areas by using HPGe detector. The concentration of 40K, 238U and 232Th were in the range 9.99-28.33 Bq.kg-1 and the net dose resulting from soil concentration varied in the range from 597 µRhr-1 to 8.34 µRhr-1 with an average value of 7.5 µRhr-1. The activities of ^{40}K and ^{238}U were 19.61 Bq.kg-1 and 62.53Bq.kg-1, respectively in that agricultural soil.

7. Bose and Mollah measured the radioactivity in non-cultivated soils in Central Virginia. He obtained of ^{137}Cs ,^{40}K, ^{232}Th and ^{238}U were in the range 0.3-30.2 Bq.kg^{-1},101 to 492 Bq.kg^{-1} 13.4 to130 Bq.kg^{-1}and 25.5 to 103.4 Bq.kg^{-1} respectively.

8. Alam *et al*., (1997), measured the activity in soil of Chittagong Hills using HPGe detector. They analyzed four radioactive nuclides such as ^{214}Bi, ^{208}TI, ^{137}Cs and ^{40}K . The average concentration and ranges are shown in following Table 2.1. This table gives an average concentration and ranges of ^{214}Bi, ^{208}TI, ^{137}Cs and ^{40}K in soil of Chittagong Hills.

Table 2.1: Average concentration and ranges of ^{214}Bi, ^{208}TI, ^{137}Cs and ^{40}K in soil of Chittagong Hills

Average	^{214}Bi (Bq.Kg^{-1})	^{208}Tl (Bq.Kg^{-1})	^{137}Cs (Bq.Kg^{-1})	^{40}K (Bq.Kg^{-1})
	36.33±15.65	14.72±8.84	2.26	350.96±113.34
Range	14.78±1.45 to 81.19±11.53	6.53±0.19 to 39.04±1.42	1.08±0.14 to 4.25±0.42	128.22±16.09 to 609.90±49.09

9. Delaune *et al.*, (1986), measured the radio nuclides concentration in Louisiana soils and sediments using Ge(Li) detector. The results of the radionuclides are given in Table 2.2.

Table 2.2: Concentration of Isotopes (Bq.kg^{-1}) in Louisiana soils and sediments

	^{214} Pb	^{228}Ac	^{208}Bi	^{212}Pb	^{208}Tl	^{137}Cs	^{212}Bi	^{40} K
Range	14-24	1-62	12-41	13-56	12-42	1-182	14-93	125-804
Average	14	36	30	33	30	23	38	472

10. Al-Azzawi *et al*., in 1999 – 2000 performed a follow-up exploration program in some areas of Basrah, through which site exposure and soil sediments, water sample and laboratory tests were conducted plus areas where most of the DU contaminated tanks were gathered, on the banks of Wafaa Al Qaied waterway causing further contamination. Results of this program indicated the existence of slightly higher radioactivity in some of the areas but generally sand storms and the weathering process contributed to the dispersion of these contaminants to nearby populated areas. Table 2.3 shows conclusions of the results of these tests and measurements. The conclusions of the results of these tests and measurements are given in this table.

Table 2.3: Conclusion of the results

Type of measurement	No. A *	No. B **	Range of Measurements	Background Levels	Units
Exposure	120	17	8.2-11.6	4-7	μR/hr
Soil	120	22	80-788	42-70	Bq/Kg
Surface and ground water	75	--	Not detected	Not detected	Bq/l
Waterway and sediment	13	10	50-85	30-40	Bq/Kg

* No. A: Number of Samples

** No. B: Number of Samples with Higher Activity

11. Pálsson *et al*., **(**2012), worked on global fallout. In the first part of the study, available global fallout data from 1954 – 1976 for 90Sr and 137Cs were reanalyzed using analysis of covariance (ANCOVA) and logarithmically transformed values of the monthly deposition density as the response variable. In the second part of the study, the behavior of 137Cs in Icelandic soils was studied. Samples were obtained from 0-5, 5-10, and 10-15 cm depths. The majority of 137Cs, 82.7% on the average, was retained in the uppermost 5 cm of the soil. This information was then used in the third part of the study, where precipitation was used to predict 137Cs deposition density in Iceland, assuming a proportional relationship as has been done successfully in a number of studies. Lastly, the performance of this traditional model was compared with the model used in the first part of the study. The aim of the fourth part of the study was to use the obtained global fallout 137Cs predictions to provide information on the long-term transfer from soil to cow's milk in Iceland, many years after deposition. Long-term transfer rates to milk many years after deposition were high in Iceland compared with most other reported data.

12. Myrick *et al*., **(**1989), determined the background radionuclide concentrations in surface soil by gamma-ray spectroscopy using Ge(Li) detector. The concentration of 232Th and 238U were found in the range between 0.10-3.4 pCi.gm^{-1} and 0.13-3.8 pCi.gm^{-1}, respectively.

2.3 Theoretical Background of Radiation

Radiation is energy traveling in the form of particles or waves in bundles of energy called photons. All atoms consist of a nucleus surrounded by a number of electrons. The nucleus consists of protons and neutrons, with the number of neutrons being slightly larger than the number of protons for most nuclei. When such unstable nuclei undergo radioactive decay as a result we get a new nucleus and different types of radiations. The kind of radiation discussed in this following section is called ionizing radiation because it can produce charged particles (ions) in matter. The characteristic of various materials to emit ionizing radiation is called radioactivity. The operation of any radiation detector basically depends on the processes in which the radiation interacts with the materials of the detector itself. The conceptual proceeding on these aspects and the basic unit of radiation and radioactivity has been discussed below.

2.4 Gamma Emission

Gamma rays are monochromatic electromagnetic radiations ranging generally from a few KeV to several MeV that are emitted from radioactive nuclei. The wavelength of gamma rays is much shorter than that of the visible light. The energy of electromagnetic radiation or photon is given by E = h¬ = h (c/ ª), where h is the Planck's constant, ¬ is the frequency; c is the velocity of light and ª is the wavelength of radiation. Gamma rays are emitted in radioactive decay along with alpha or beta radiations. They are absorbed exponentially in materials, but in view of their great penetrating power, only thick blocks of concrete, lead or other high-density materials can reduce their intensity to small value. The gamma rays can deliver a whole body dose either from outside or inside the body due to their high penetrating power. The element does not change due to gamma radiation but will change depending on the accompanying alpha or beta radiation (Hall, 1976).

2.5 Gamma Ray Spectroscopy

The gamma ray spectrum is defined as the pulse height distribution obtained by gamma ray spectrometer. The technique of measurements and data analysis of gamma ray spectrum is called gamma ray spectrometry. It is widely used in any radioactive material having facilities owing to its high sensitivity. Also it is an effective measuring method for the environmental radiation monitoring and for analysis of low-level radioactivity because it has high-resolution power which enables us to make rapid and simultaneous analysis for many nuclides and has very small background counts which are included in peak areas of gamma ray. Furthermore, many samples can be provided for gamma ray measurement by the detector. There are different types of detectors, which are given in Table 2.4 (Cember, 1989). Among all these detectors high purity germanium (HPGe) detector has been employed in the present study. It is able to determine radionuclides both qualitatively and quantitatively. Gamma rays emitted from sources interact with the semiconductor device in different manners depending upon its energy and environment which are discussed below.

In this way the gamma spectra obtained in the personal computer analyzer (PCA) or multichannel analyzer (MCA) coupled with High Purity Germanium (HPGe) detector system is the direct output of the gamma rays interaction with an absorbing material.

Table 2.4: Comparison among different detectors

Detector type	Normally Achieved Dimensions	Window Thickness Achieved	Useful Photon Energy Range	Typical Energy Resolution FWHM	Peak-to-Compton Ratio
Lithium drifted silicom, Si (Li)	Planar geometry Area 30-80 mm^2 Thickness 3-5 mm	0.1	1KeV-60 KeV	160-200 eV (at 5.9 KeV)	-
High purity p-type Germanium (ion implant thin Window)	Planar geometry Area 30-1000 mm^2 Thickness 5-10 mm	0.3	5 KeV- 1 MeV	160-360 eV (at 5.9 KeV)	-
HPGe Lithium Drifted Germanium; (HPGe)	Coaxial geometry; Sensitive volume to provide up to 35% efficiency	300-1000	50 KeV-10 MeV	1.8-2.2 KeV (at1.33 MeV)	up to 50
High purity p-type Germanium; (HPGe)	Coaxial geometry; Sensitive volume to provide up to 35% efficiency	300-600	40 KeV-10 MeV	1.8-2.2 KeV (at 1.33 MeV)	up to 50
High purity n-type Germanium; (HPGe)	Coaxial geometry; Sensitive volume to provide up to 35% efficiency	0.1	5KeV-10 MeV	1.7-2.2 KeV (at 1.33 MeV)	up to 50

2.6 Interaction of Radiation with Matter

In order to understand the detectors used for gamma and x-ray detection and to be able to select one for a particular measurement, it is necessary to review the ways in which gamma rays and x-rays interact with matter. There are several processes by which the electromagnetic fields of a photon interact with an absorbing material. These are classified as major, minor and negligible. Table 2.5 gives the classification of photon interaction with matter (Abani, 1988).

Table 2.5: Classification of photon interactions with matter

	Type of interaction		
	Absorption	Scattering	
Interaction with		Elastic (Coherent)	Inelastic (Incoherent)
Atomic Electron	Photoelectric Effect ²$_{pe}$ ~ Z^4 (low energy) ~ Z^5 (high energy)	Rayleigh Scattering ±$_R$ ~ Z^2	Compton Scattering ± ~ Z
Nucleons	Photonuclear Reactions (γ,n), (γ,p), (γ,f) etc. ±$_{pn}$ ~ Z (h¬ ≥10 Mev)	Elastic Nuclear Scattering	Nuclear Resonance Scattering
Electric field of Surrounding charged particles	Pair Production Field of Nucleus K_n ~Z^2 (h¬ ≥1.02 MeV Field of Electron K_e ~Z(h¬ >2.04MeV)	Delbruck Scattering	…...

The major interactions are

(1) Photoelectric effect

(2) Compton scattering and

(3) Pair production

As a result of this processes the emission of electrons occur from the absorber and as these electrons when passes through the matter, they create electron-hole pairs. Thus the passage of an ionizing direction through the detector material results in energy dissipation through the creation of ionization. This creation of ionization is converted into an electrical signal which is then amplified by amplifier circuit.

2.7 Units of Radioactivity

The radioactivity of a source is defined in terms of the number of disintegration it undergoes in one second. The associated units of the radioactivity are discussed below.

Becquerel

The S.I. unit of radioactivity is called Becquerel. The Becquerel (Bq) is that quantity of radioactive material in which one atom is transformed per second.

1 Bq =1 transformation per second = 1 tps.

It must be emphasized that, although the Becquerel is defined in terms of a number of atoms transformed per second, it is not a measure of rate of transformation. The Becquerel is a measure only of quantity of radioactive material (Cember, 1989).

For many purposes, the Becquerel is a very small quantity of activity, and multiples of the Becquerel is commonly used.

Curie

The curie, symbolized by Ci, is the unit for quantity of radioactivity that was used before the adoption of the SI units and the Becquerel. The curie, which originally was defined as the activity of 1 gram ^{226}Ra, is more explicitly defined as:

The curie is the activity of that quantity of radioactive material in which 3.7×10^{10} atoms are transformed per second. The curie is related to the Becquerel by

$$1 \text{ Ci} = 3.7\times10^{10} \text{ Bq.}$$

For health physics, as well as for many other purposes, the curie is a very large amount of activity.

2.8 Radiation Dosimetry

Radiation dosimetry tells us about precise unit of radiation dose that is suitable either for radiation protection or radiation therapy. For radiation protection purposes, the mostly common used ‘dosimeter’ is a piece of dental film with a paper clip attached. However, radiation absorbed by the body is energy dependent and it is thus necessary to talk and distinguish about radiation absorbed dose and radiation exposure.

Absorbed Dose

Radiation damage depends on the absorption of energy from the radiation, and is approximately proportional to the concentration of absorbed energy in tissue. The amount of energy actually deposited by radiation in cells is known as absorbed dose or absorbed energy.

Gray

The S.I. unit of absorbed dose is called the gray (Gy). One gray is an absorbed radiation dose of one joule per kilogram. 1 Gy = 1 J/kg. The gray is universally applicable to all types of ionizing radiation dosimetry like irradiation due to external fields of gamma rays, neutrons, or changed particles, as well as that due to internally deposited radioisotopes.

Rad

Before the universal adoption of the SI units, radiation dose was measured by a unit called the rad (Radiation Absorbed Dose). One rad is an absorbed dose of 100 ergs per gram.

1 rad = 100 ergs/gm.

Since 1 J = 10^7ergs and 1 kg = 1000 gm, 1 Gy = 100 rads.

Exposure

Exposure is a quantity expressing the amount of ionization caused in air by X-ray or gamma radiation.

Exposure Unit (X- unit)

Exposure Unit is expressed by X-unit in short. One X-unit is defined as that quantity of X-ray or gamma radiation that produces ions (in air) carrying 1coulomb of charge (either sign) per kilogram of air.

1 X-unit = 1 C/kg (in air).

X-unit is limited to x-rays or gamma rays whose quantum energies do not exceed 3Mev.

Roentgen

Before the SI unit of exposure was adopted, the unit of x-ray exposure was called roentgen (R). One roentgen was defined as that quantity of x-ray or gamma radiation that produces ions carrying one statcoulomb of charge (either sign) per cubic centimeter of air at 0^0C and 760mm Hg. 1 R = 1 SC/cm^3.

The relationship between the exposure unit and the roentgen can be written as,

1 X-unit = 3881 R.

KERMA (Kinetic Energy Released in the Medium)

For practical convenience, the concept of air Kerma is used to specify the radiation quantity instead of exposure. Air Kerma gives an idea about the energy transferred per unit mass of air

– a unit introduced by ICRU to describe the initial interaction between radiation and an electron in certain medium.

The initial kinetic energy of the primary ionizing particles (e.g. photoelectrons, Compton electrons) produced by the interaction of the incident indirectly ionizing radiation (e.g. x-rays, gamma rays, fast neutrons) per unit mass of the interacting medium is called the Kerma. Kerma in SI system is measured in JKg^{-1} or Gy.

The usefulness of air Kerma can be extended to the determination of the radiation output at a specified distance from a radiation source in terms of mGy per hour. The air Kerma rate at 1 meter and the activity of gamma source can be correlated using exposure rate constant applicable for that source. For example, 1 GBq of Cobalt-60 gives an Air-Kerma output of 0.31 $mGyh^{-1}$ (Johns and Cunningham, 1964).

2.9 Relative Biological Effectiveness

The comparison of relative toxicity between alpha, beta and gamma radiation is defined on the basis of equal amounts of energy absorption. Generally, the higher the rate linear energy transfer (LET) of the radiation, the more effective it is in damaging an organism. The ratio of the amount of energy of 200keV X-rays required to produce a given effect to the energy required of any radiation to produce the same effect is called the relative biological effectiveness, abbreviated as RBE. Here, the 200keV X-rays energy is termed as reference radiation. The RBE of a specific radiation depends on the exact biological effect on a given species of organism under a given set of experimental conditions (Cember, 1989). The term RBE is thus restricted in application to radiation biology.

2.10 Quality Factor and Dose Equivalent

In biological systems, the same degree of damage is not necessarily produced by the same absorbed dose of different types of radiation. The biological damage due to 1Gy of alpha dose will be different as a whole than that of due to 1Gy of gamma dose. 1Gy of alpha dose is approximately 20 times more effective in causing biological damage compared to 1Gy of gamma dose (Islam, 2009). However, quality factor (QF) reflects the ability of any particular type of radiation to cause damage. The quality factor is used to modify the absorbed dose from one type to the other types of radiation.

When absorbed dose of any radiation is multiplied by the respective quality factor, the obtained quantity is known as the dose equivalent.

The S.I. unit of dose equivalent is sievert, Sv. And the C.G.S. unit of dose equivalent is rem. 1 Sv = 100 rem.

$$\text{Dose equivalent (Sv)} = \text{Absorbed dose (Gy)} \times QF$$

$$\text{Dose equivalent (rem)} = \text{Absorbed dose (rad)} \times QF$$

The value of the quality factor is found to depend on the density of ionization caused by the radiation in tissue. The values of QF for the most commonly encountered radiations are presented in Table 2.6 (Knoll, 1989).

Table 2.6: Quality Factor (QF) for different radiations

Radiation	QF
x-rays, γ-rays, electrons	1
Thermal neutrons	2.3
Fast neutrons, Protons	10
Alpha particles	20

2.11 Effective Dose Equivalent

For the purposes of setting radiation safety standards, it is assumed that the probability of a radiation effect like stochastic effect in any tissue is proportional to the dose equivalent to that tissue. When the dose equivalent of any tissue is multiplied by the weighting factor of that tissue, we get the amount of effective dose equivalent.

Mathematically, Effective dose equivalent, $H_E = \sum W_T H_T$

Where, W_T is called the weighting factor for tissue T and H_T is the dose equivalent to that tissue T. The weighting factors for various tissues are based on the relative susceptibility of the respective organs to stochastic effects. Table 2.7 (Cember, 1989) points out the weighting factors for different tissues at risk of stochastic effects.

Table 2.7: Weighting factors for different tissues at risk of stochastic effects

Tissue	Weighting factor, W_T	Comments
Gonads	0.25	Genetic risk to first 2 generations
Breast	0.15	Average for all ages of both sexes
Red bone marrow	0.12	Leukemia
Lung	0.12	Cancer
Thyroid	0.03	Fatal Cancer
Bone surface	0.03	Osteosarcoma
Remainder of the body	0.30	Cancer

2.12 Biological Effects of Radiation

The interaction of ionizing radiation with the human body, arising either from external sources outside the body or from internal contamination of the body by radioactive substances, leads to biological effects which may later come as clinical symptoms (Martin and Harbison, 1979). The nature and severity of these symptoms and the time at which they appear depend on the amount of radiation absorbed and the rate at which it is received.

While ionizing radiation has many uses, some of great benefit to mankind, it is also true that its beneficial use must be carefully weighed against possible delirious effects. Ionizing radiation is not only potentially dangerous, but in fact lethal, if misused. The effects which occur depend on the types of cells which absorb the radiation, the total radiation dose, the length of time over which the exposure occurred, and whether the body is able to affect any repair of the damage. Differences in biological effects are the result of differences in these factors. The biological effects of radiation may be broadly classified into two categories, viz. non-stochastic (deterministic) and stochastic effect (Cember, 1989).

Non-stochastic Effects

Effects with a threshold dose and for which the severity of the injury increases with dose are known as non-stochastic effects. Non-stochastic effects are characterized by three quantities: First, a certain minimum dose must be exceeded before the particular effect is observed. Additionally, the magnitude of the effect increases with the increase of the dose. Furthermore, there is a clear causal relationship between dose agent and effect in a given individual. In a word, in non-stochastic effect, a certain minimum dose must be exceeded before the particular effect is observed, and the magnitude of the effect increases with the increase of the dose. For example, a person must exceed a certain amount of alcohol before he shows signs of drinking. After that, the effect of the alcohol depends on how much he drank. Because of the minimum dose that must be exceeded before an individual shows the effect, non-stochastic effects are also called threshold effects. Non-stochastic effects are also can be termed as early radiation effects. Examples: Erythema, cataract, radiation damage to the gut and the production of the temporary or permanent sterility in both males and females. When the magnitude of the effect or the proportion (percent) of individuals who respond at a given dose is plotted as a function of dose to obtain a quantitative relationship, the dose-response curve A of Fig 2.1 is obtained. In Fig 2.1, A point ‘a’ represents the threshold point.

Stochastic Effects

Stochastic effects are those effects that occur by chance. They occur among unexposed people as well as among exposed individuals. Stochastic effects are therefore not clearly related to exposure. The main stochastic effects are cancer and genetic effects. The result of exposure to a carcinogen (substance that produces cancer, tobacco) increases the probability of occurrence of the effect. In this case, the increase in probability of the effect is directly proportional to the dose.

People may develop cancer whether they are exposed to carcinogenic agents or not. However, exposure to carcinogen increases the likelihood of cancer. Lung cancer is found in a much higher proportion of cigarette smokers than among non-smoker, and among cigarette smokers, lung cancer is seen in a greater proportion of heavy smokers than in light smokers.

In other word, as the name implies, stochastic effects occur in a statistical manner. For radiation induced effects, the probability of a stochastic effect occurring depends upon the radiation dose received, but there is no such thing as a “safe dose” i.e., no threshold dose exists below which such an effect can’t occur. Two general types of stochastic effect are well recognized. The first occurs in somatic cells and may result in the induction of cancer in the exposed person; the second occurs in cells of the germinal tissue and may result in hereditary disorders in the progeny of those irradiated (Islam, 2009).

Another important point concerning such stochastic effects as mentioned earlier, is that the severity of the effect is unrelated to radiation dose. Thus, as the radiation dose increases, the probability of cancer induction increases, but the severity of the cancer does not depend upon the radiation dose which caused it.

Stochastic effects are often called linear, zero-threshold dose response effects. According to the linear, zero-threshold model, every increment of radiation, no matter how small, carries with it a corresponding increase in risk of stochastic effect (Cember, 1989).

When the frequency of occurrence or percent response of a stochastic effect is plotted against the increase of dose to obtain the quantitative relationship, a linear dose-response curve (B) of Fig 2.1 is observed.

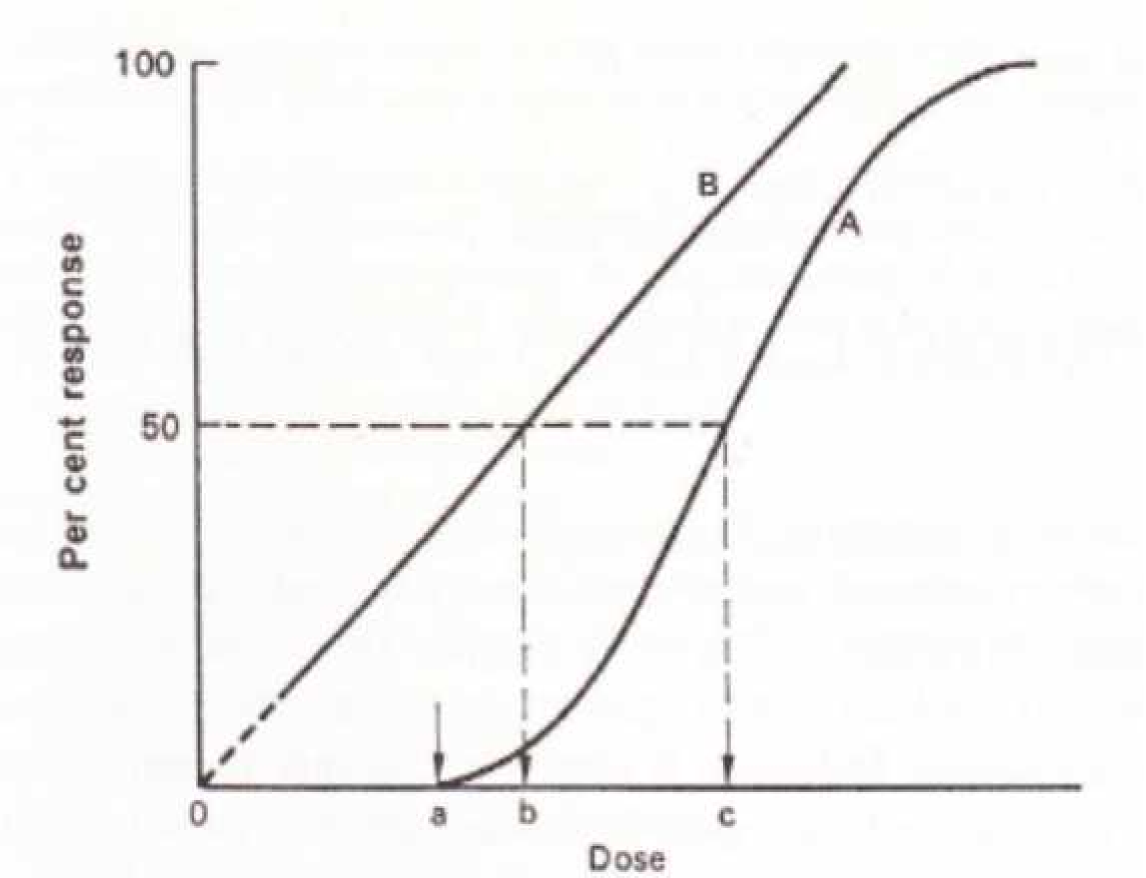

Fig 2.1: Dose-response curves for non-stochastic (A) and stochastic (B) effects.

2.13 The Interaction of Radiation with Cells

The basic difference between nuclear radiations and the more commonly encountered radiations such as heat and light is that they have sufficient energy to cause ionization. In water, of which cells are largely composed, ionization can lead to molecular changes and to the formation of chemical species of a type which are damaging to the chromosome material. The damage takes the form of changes in the construction and the function of the cell. In the human body, these changes may manifest themselves as clinical symptoms such as radiation sickness, cataracts or in the longer term, cancer. The processes leading to radiation damage are complex and are often considered in four stages and are described below.

(1) The initial physical stage:

This stage lasts only a minute fraction (~10^{-16}) of a second in which energy is deposited in the cell and causes ionization. In water the process may be written as, $H_2O \rightarrow H_2O^+ + e^-$

Where H_2O^+ is positive ion and e^- is the negative ion.

(2) The physico-chemical stage:

This stage lasts about 10^{-6} seconds in which the ions interact with other water molecules resulting in a number of new products. For example, the positive ion dissociates,

$$H_2O^+ \rightarrow H^+ + OH$$

The negative ion that is, the electron attaches to a neutral water molecule which then dissociates,

$$H_2O + e^- \rightarrow H_2O^-$$

$$H_2O^- \rightarrow H + OH^-$$

Thus the products of the reactions are H^+, OH^-, H and OH. The two former ions which are present to quite a large extent in ordinary water, take no part in subsequent reactions. The other two products, H and OH are called the free radicals, which are they have an unpaired electron and are chemically highly reactive. Another reaction product is hydrogen peroxide H_2O_2 which is a strong oxidizing agent. $OH + OH \rightarrow H_2O_2$

(3) The chemical stage:

This stage lasts a few seconds in which the reaction products interact with the important korganic molecules of the cell. The free radicals and oxidizing agents may attack the complex molecules which form the chromosomes. They may attach themselves to a molecule or cause links in long chain molecules to be broken.

(4) The biological stage:

In this stage, the time scale varies from several minutes to several years depending on the particular symptoms (Martin and Harbison, 1979). The chemical changes discussed above can affect an individual cell in number of ways. For example, they may result in,

(a) The early death of the cell.
(b) The prevention or delay of cell division.
(c) A permanent modification which is passed on to daughter cells.

2.14 Acute and Chronic Exposure

In health physics we are concerned with two types of exposure:

(1) A single accidental exposure to a high dose of radiation during a short period of time, which is commonly called acute exposure, and which may produce biological effects within a short time after exposure;

(2) Long-term, low level overexposure due to improper or inadequate protective measures, commonly called continuous or chronic exposure, where the results of the overexposure may not be apparent for years.

Acute Exposure

Effects of radiation due to acute exposure occur for a large dose of radiation delivered during a short period of time. These effects of radiation are deterministic which have threshold level. Below the level, the effect will probably not occur but above which the effect is expected. In this case, the severity of the effect increases as the dose increases and it may produce biological effects within a short time after exposure.

Chronic Exposure

Biological effects of radiation also occur due to chronic exposure which is a relatively small amount of radiation exposure over a long period of time. In this case the result of the overexposure may not be apparent for years. There is no threshold value for occurrence of the biological effects. These effects include different types of cancer.

2.15 The Somatic and Hereditary Effects of Radiation

The effects of radiation on the human body are the result of damage to the individual cells. These effects may be conveniently divided into two classes, namely somatic and hereditary. The somatic effects arise from damage to the ordinary cells of the body and affect only the irradiated person. The hereditary effects, on the other hand, are due to damage to the cells in the reproductive organs, the gonads (Lea, 1965). The important difference is that, in this case, the damage may be passed on to the person’s children and subsequently to later generations. The somatic and hereditary are discussed below.

The Somatic Effects of Radiation

The somatic effects are of two types:

- Early radiation effects and
- Late effects.

Early Radiation Effects

The early radiation effects are those which occur in the period from a few hours up to a few weeks after an acute exposure that is a large dose received over a few hours. The effects are due to major depletions of cell populations in a number of body organs due to cell-killing and the prevention or delay of cell division. The main effects are bone marrow, gastrointestinal or neuromuscular damage depending on the dose received. Acute absorbed doses above about 1 Gy give rises to nausea vomiting (Bond *et al*., 1965). This is known as radiation sickness and it occurs a few hours after exposure, as a result of damage to cells lining the intestine. Absorbed doses above about 2 Gy can lead to death, probably 10 to 15 days after exposure (Grosch and Hopwood, 1979).

Since not all organs and organ systems are equally sensitive to radiation, the pattern of response, or disease syndrome, in an overexposed individual depends on the magnitude of the dose. There is no well- defined threshold dose below which there is no risk of death due to acute doses, though below about 1·5 Gy the risk of early death would be very low. Similarly, there is no well-defined point above which death is certain, but the chances of surviving an acute dose of about 8 Gy would be very low (Bond *et al*., 1965).

In order of increasing severity, the acute radiation syndrome in subdivided into three categories:

(1) The haemopoietic syndrome.
(2) The gastrointestinal syndrome.
(3) The central nervous system syndrome.

Certain effects are common to all categories and these include;

- Nausea and vomiting, Malaise and fatigue, Temperature increase, Blood changes.

(1) Haemopoietic Syndrome

- Appears a gamma dose of 2 Gy (200 rads).
- Depression or ablation of the bone marrow and the physiological consequences are seen.

- The platelet count falls steadily until a minimum is reached about a month after exposure.
- The degree of change in the blood, as well as rate of change is a function of radiation dose.
- Nausea, vomiting begin within in several hour of exposure.
- Hair loss which is almost seen in the 2nd or 3rd week after exposure.
- Death may occur between 1 to 2 months after the exposure if medical treatment is not sought or successful.

(2) Gastrointestinal Syndrome

- Appears following a total body dose of about 10 Gy or greater.
- Bone marrow is completely destroyed.
- Severe nausea, vomiting and diarrhea begin very soon or immediately after exposure.
- Death, within 1 to 2 weeks after exposure, is the most likely outcome of the exposure.

(3) Central Nervous System Syndrome

- Appears after a total body dose in excess of about 20 Gy.
- Damages the central nervous system as well as all the other organ systems in the body.
- Unconsciousness follows within minutes after exposure.
- The rapidity of onset of unconsciousness is directly related to dose.
- Death is a matter of hours to several days (Paul, 2007).

Another effect which shows up soon after an acute over exposure to radiation is erythema that is reddening of the skin. Since the skin is located on the surface of the body it is subject to more radiation exposure than most other tissues. This is especially true for beta rays and low energy X-rays. An exposure of about 3 Gy of low energy X-rays will result in erythema and larger exposures may lead to other symptoms such as changes in pigmentation, blistering and ulceration. Besides, 1·25 Gy to the ovaries can result in prolonged or permanent suppression of menstruation in about 50% of women. 6 Gy to the ovaries or testicles can result in permanent sterilization. 0·50 Gy to the thyroid gland can result in benign (non-cancerous) tumors (Martin and Harbison, 1979).

The levels of exposure both of workers and of the public arising from the nuclear energy industry or from industrial and medical applications of radiation are far below than the levels which would induce early effects. Such high doses could only be received in the unlikely event of a major nuclear accident. However, the low doses received in normal operations may cause harmful effects in the long term and these are discussed as late effects.

Late Effects

- Can develop many years after exposure.
- May occur in person who has been exposed to acute exposure.
- May also arise from chronic exposure.
- Delayed effects of radiation are varies forms of cancer, cataract and sterility.

A brief description of cancer, cataract and sterility are given below.

1 Cancers (induced by radiation):

- Develop many years after the radiation was received.
- Radiations can produce cancers in the blood-forming tissue, skin, bone, lung and thyroid.
- Minimum latent period for most cancers is 10 years or more. (Paul, 2007)

The risks of radiation induced cancer in the various body organs are under continuous review, as new experimental data become available. Some estimations of the risk of fatal cancers, derived from the work of Throne et al., are shown in the following Table 2.8.

Table 2.8: Nominal risk of fatal cancer (Martin and Harbison, 1979)

Effect	Tissue at risk	Cases per 10^6 per mSv	
		Male	Female
Leukemia	Red bone marrow	3	3
Breast cancer	Female breast	-	5
Lung cancer	Lung	2	2
Thyroid cancer	Thyroid	1	1
Bone sarcoma	Cells on bone surfaces	0·5	0·5
Liver cancer	Liver	1	1
Other cancers	All other tissues	3	3
Total	Whole body	10·5	15·5

The estimations are expressed as the number of cancer cases expected per millions per mSv. This implies that if one million males each received a dose equivalent of 1 mSv, the number of fatal cancers attributable to the radiation would be about 10 and this would appear over a period of few decades. In the case of females, the number of radiation induced cancers would be expected to be about 15 because of the additional risk of breast cancer (Casarett, 1968). The average risk of fatal cancers in a mixed population would be about 13 cases per million per mSv. To put this estimations of the risk of radiation induced cancer into perspective, it should be noted that in a typical population of 1 million people, there about 2000 deaths from spontaneous cancers every year (Fabricant, 1972).

2 Cataracts:

A mentionable late effect of radiation is cataract formation in the lens of the eye. The word cataract is used to describe a loss of transparency of the lens of the eye. In this case it appears that there is a threshold dose, below which cataracts can't be induced. This is of the order of 15 Sv, and so by setting dose limits so that the total dose to the lens of the eye over the whole working lifetime in below this value, the possibility of cataract formation due to radiation can be avoided (Martin and Harbison, 1979).

- A loss of transparency of the lens of eye.
- Latent period is several years.
- There is a threshold dose, below which cataract can not be induced.
- 500 – 1000 rad will produce significant cataract.

3 Fertility:

Another possible late effect of radiation is permanent histological sterility, the complete absence of gametes, requires absorbed doses of photons to the gonads of 3·5 Gy to 6 Gy for men and 2·5 Gy to 6 Gy for women.

- Sterility can appear as an acute symptom.
- Permanent sterility requires absorbed doses to the gonads of
- 3.5 to 6 Gy for male
- 2.5 to 6 Gy for female (Paul, 2007).

There is some evidence from animal experiments that exposure to radiation may slightly reduce the life expectation of individuals who do not exhibit any specific radiation induced symptoms. Observations of human populations exposed at relatively high levels indicate that life shortening doesn't occur at all, if occurred it is very slight and almost certainly less than 1 year per Sv (Islam, 2009).

The Hereditary Effects of Radiation

The hereditary effects of radiation result from damage to the reproductive cells. This damage takes the form of alterations, known as genetic mutations, in the hereditary material of the cell.

It has already been mentioned that reproduction occurs when the ovum is fertilized by a sperm. As a result, the offspring receives a complete set of genetic material from each parent. Thus the child receives two complementary sets of genes, one from each of its parents. In general, it is found that one gene is ‘dominant’ and the other ‘recessive’.

The dominant gene determines the particular characteristics with which it is associated. Recessive genes are only recognized when by chance two of the recessive type genes come together. A considerable number of diseases are associated with recessive genes and will therefore only manifest them when both parents have the same recessive genes. Spontaneous mutation accounts for the fact that an appreciable fraction of the world’s population suffers from one of the 500 or more defects or diseases attributable to hereditary effects.

Radiation can induce gene mutations which are indistinguishable from naturally occurring mutations. It should be noted in passing that heat and chemicals can also cause mutations. Mutated genes are generally recessive and so it is generally assumed that all mutations are harmful. Since ionizing radiation can cause an increase in the mutation rate, its use will increase the number of genetically abnormal people present in future generations. Clearly, the consequences of excessive genetic damage would be very serious indeed and strict control must be exercised over the radiation exposure of the general population. The risks of hereditary effects due to exposure of the gonads are very uncertain. ICRP estimated the risk of serious hereditary ill-health within the first two generations following the irradiation of either parent to be about 10 per million per mSv. Over all generations, the risk would be about twice this value. Clearly, only that exposure which occurs up to the time of conception can affect the genetic characteristics of the offspring, and since the mean age of childbearing is about 30 years, only a proportion of the dose received by a typical population will be genetically harmful. The total genetic risk in all generations averaged over both sexes and over all ages, is therefore about 8 serious effects per million per mSv (Martin and Harbison, 1979).

All the available information leads to the conclusion that the chance of developing any of the effects of radiation increases as the radiation dose increases. It is thus the responsibility of those working with ionizing radiation to keep the quantity of absorbed radiation by themselves and other individuals to an absolute minimum and certainly within the limits recommended by the Nuclear Safety and Radiation Control Act-1993 and Nuclear Safety and Radiation Control Rules-1997 (Hasan *et al.*, 2013).

Table 2.9: Comparison of the average concentration of ^{226}Ra, ^{232}Th and ^{40}K in different soil samples (present study) with those of other published data in different countries

Country	Radioactivity Concentration(Bq/kg)			Reference
	^{226}Ra	^{232}Th	^{40}K	
India	44.21	174.48	93.10	Singh *et al.*, 2005
Egypt	17	18	320	UNSCEAR, 2000
United States	40	35	370	UNSCEAR, 2000
Argentina	-	-	650	UNSCEAR, 2000
China	32	41	440	UNSCEAR, 2000
China	40.3	59.6	751.2	Lu *et al.*, 2012
Cameroon	-	16.67	186.96	Tchokossa *et al.*, 2012
Hong Kong SAR	59	95	530	UNSCEAR 2000
India	29	64	400	UNSCEAR, 2000
Japan	33	28	310	UNSCEAR, 2000
Korea, Rep. of	-	-	670	UNSCEAR, 2000
Iran (Islamic Rep. of)	28	22	640	UNSCEAR, 2000
Denmark	17	19	460	UNSCEAR, 2000
Ghana	13.61	24.22	162.08	Faanu *et al.*, 2011
Nigeria	41.1	78.6	223.5	Umar, (2012)
Belgium	26	27	380	UNSCEAR, 2000
Luxemburg	35	50	620	UNSCEAR, 2000
Switzerland	40	25	370	UNSCEAR, 2000
Bulgaria	45	30	400	UNSCEAR, 2000
Malaysia	99.13	139.98	598.24	Saat *et al.*, 2011
Romania	32	38	490	UNSCEAR, 2000
Greece	25	21	360	UNSCEAR, 2000
Portugal	44	51	840	UNSCEAR, 2000
Spain	32	33	470	UNSCEAR, 2000

Country	Radioactivity Concentration(Bq/kg)			Reference
	^{226}Ra	^{232}Th	^{40}K	
USA	40	35	370	UNSCEAR, 2000
Jordan	56	29	501	New York: UNSCEAR, 2000
Cyprus	17	-	140	UNSCEAR, 2000
Armenia	46	30	360	UNSCEAR, 2000
Lithuania	16	25	600	UNSCEAR, 2000
Ireland	37	26	350	UNSCEAR, 2000
Russia	19	30	520	UNSCEAR, 2000
OAP data	172	211	511	UNSCEAR, 2000
Khulna, Bangladesh	50.46	85.42	900.79	Present study (Soil)
Khulna, Bangladesh	52.22	90.65	870.45	Present Study (Sediment)
Worldwide mean	30	35	400	UNSCEAR, 2000

Table 2.10: Comparison of the average outdoor annual effective dose (mSvyr^{-1}) due to the intake of natural radionuclide of ^{226} Ra, ^{232}Th &^{40} K from the soil samples collected from Rupsha river side area, Khulna (present study) with those obtained in other published data

Country	Outdoor annual effective dose(mSvyr^{-1})	References
Khulna, Bangladesh	0.13	Present Study (Soil)
Khulna, Bangladesh	0.13	Present Study (Sediment)
China	0.106±0.004	Lu *et al.*, 2012
Ghana	0.17±0.09	Faanu *et al.*, 2011
China	0.074	Zhonghal *et al.*, 2011
India	0.15-0.32	Mehra *et al.*, 2010
Pakistan	0.34±0.12	Rahman, 2007
Barapukuria Coal Mine (BD)	0.083	Hasan, 2013
UNSCEAR-2000	0.115	UNSCEAR, 2000

Table 2.11: Comparison of the absorbed dose rate, D (nGyh^{-1}) due to the intake of natural radionuclide of ^{226} Ra, ^{232}Th &^{40} K from the soil samples collected from Rupsha river side area, Khulna (present study) with those obtained in other published data

Country	Absorbed Dose Rate, D (nGyh^{-1})	References
Khulna, Bangladesh	106.13	Present Study (Soil)
Khulna, Bangladesh	105.03	Present Study (Sediment)
China	86.6±3.4	Lu *et al*., 2012
Cameroon	33.73	Tchokossa *et al*., 2012
China	60	Zhonghal *et al*., 2011
India	185.32	Mehra *et al*., 2010
India	60.40-82.15	Mehra *et al*.,2010
SonadiaIsland,Bay-of Bengal	84.67	Chowdhury *et al*., 2012
Barapukuria Coal Mine,Dinajpur	67.14	Hasan, 2013
Kuakata Sea Beach,Patuakhali	110.04	Islam, 2012
UNSCEAR	55	UNSCEAR, 2000

Table 2.12: Comparison of average concentration of ^{226}Ra, ^{232}Th , ^{40}K & ^{137}Cs in different soil & sediment samples (present study) with those of other published data in different places of Bangladesh

Different Location of Bangladesh	Radioactivity Concentration(Bq/kg)			
	^{226}Ra	^{232}Th	^{40}K	^{137}Cs
Jessore (sediment) (Kabir *et al*., 2008)	42.90	47.85	502.73	ND
Chittagong(sediment) Karnaphuli River (Chowdhury, 1999)	35.9	65.5	272	2.2
Bay-of-Bengal(sediment) (Sharif *et al*., 1994)	18-101	-	138-1318	ND
Sonadia Island(Soil) Bay-of-Bengal (Chowdhury *et al*., 2012)	33.4	46.6	831	ND
BhawalGahr(soil) Gazipur (Islam *et al*., 2015)	66.68	101.64	474.81	ND
TRIGA MARK-II (Soil) AERE,Savar	35.38	45.91	656.53	ND
Barapukuria Coal Mine,Dinajpur (Hasan *et al*., 2013)	23.54	52.10	603.17	ND
Kuakata Sea Beach,Patuakhali (Islam *et al*., 2012)	29.19	90.56	874.89	ND
Dhaka City (Miah *et al*., 1998)	21-43	9-22	402-705	ND
Present Study(Soil) Khulna	50.16	77.23	864.63	ND
Present Study(Sediment) Khulna	50.46	73.99	881.49	ND

CHAPTER III

Methodology

3.1 Introduction

Sample collection, preparation and measurement procedures are considered very important for gamma spectrometry. In this chapter the sample collection, preparation and measurement procedures are described in details.

3.2 Study Area

Bangladesh is a small country, mostly dependent on agriculture and the agriculture is fully dependent on soil, sediment and water. Khulna is the third-largest city in Bangladesh located in the south-west corner which coordinates is 22°49.0′N 89°33.0′E and Khulna has an old river port located on the Rupsha River. It is an important hub of Bangladeshi industry and hosts many national companies. Rupsha River is the area of interest in the present study, which is located in Rupsha Upazilla under Khulna district of Khulna division. Rupsha River is the main source of water for the agriculture and industry of Khulna city. The locations of sample collection under current study are shown in Figure 3.1 and 3.2.

3.3 Sampling Locations

A total of 44 samples (10-soil, 10-sediment, and 24-water) were collected from in and around the Rupsha River located at Rupsha area, Khulna during the period of 30/04/2015 to 02/05/2015. Among 24 water samples, 10 were surface water and 14 were tube well water. The sampling area of Rupsha River is in between 22° 46′4.17´´N to 22° 50′31.86´´N and 89° 33′11.39´´E to 89° 36′5.85´´E.

3.4 Sample Collection and Preparation

It was started earlier section that 10 soil samples, 10 sediment samples and 24 water samples were collected from in and around of Rupsha river. The soil, sediment and river water samples were collected from equidistant locations with a distance of about 1 km from each other. About 0.7 to 1 kg of soil and sediment samples was collected from each sampling location. The soil samples were collected around the river and the sediment samples were collected about 20 cm deep of the river. Then the samples were packed separately in plastic bag. The tube well water samples were collected from river side tube well and river side village tube well in 0.5 liters plastic bottles. All samples were marked with identification parameters such as sample no, location, date etc. and transported to the laboratory of the Health Physics and Radioactive Waste Management Unit (HPRWMU), Bangladesh Atomic Energy Commission (BAEC), Savar, Dhaka for processing and characterization. Table 3.1 shows detailed of the collected samples for study (with location- local name).

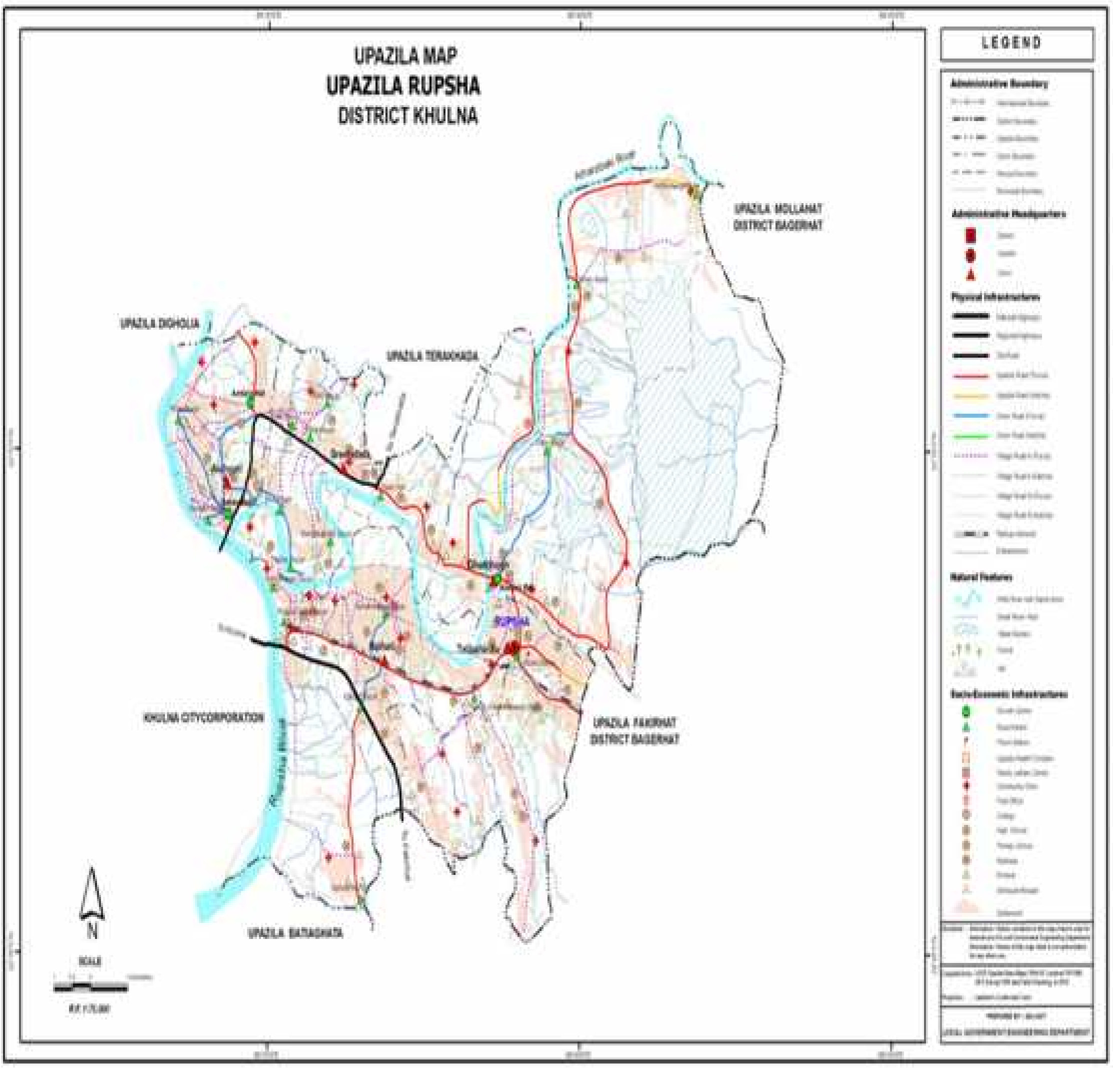

Fig 3.1: Location map of the Rupsha River, Khulna, Bangladesh

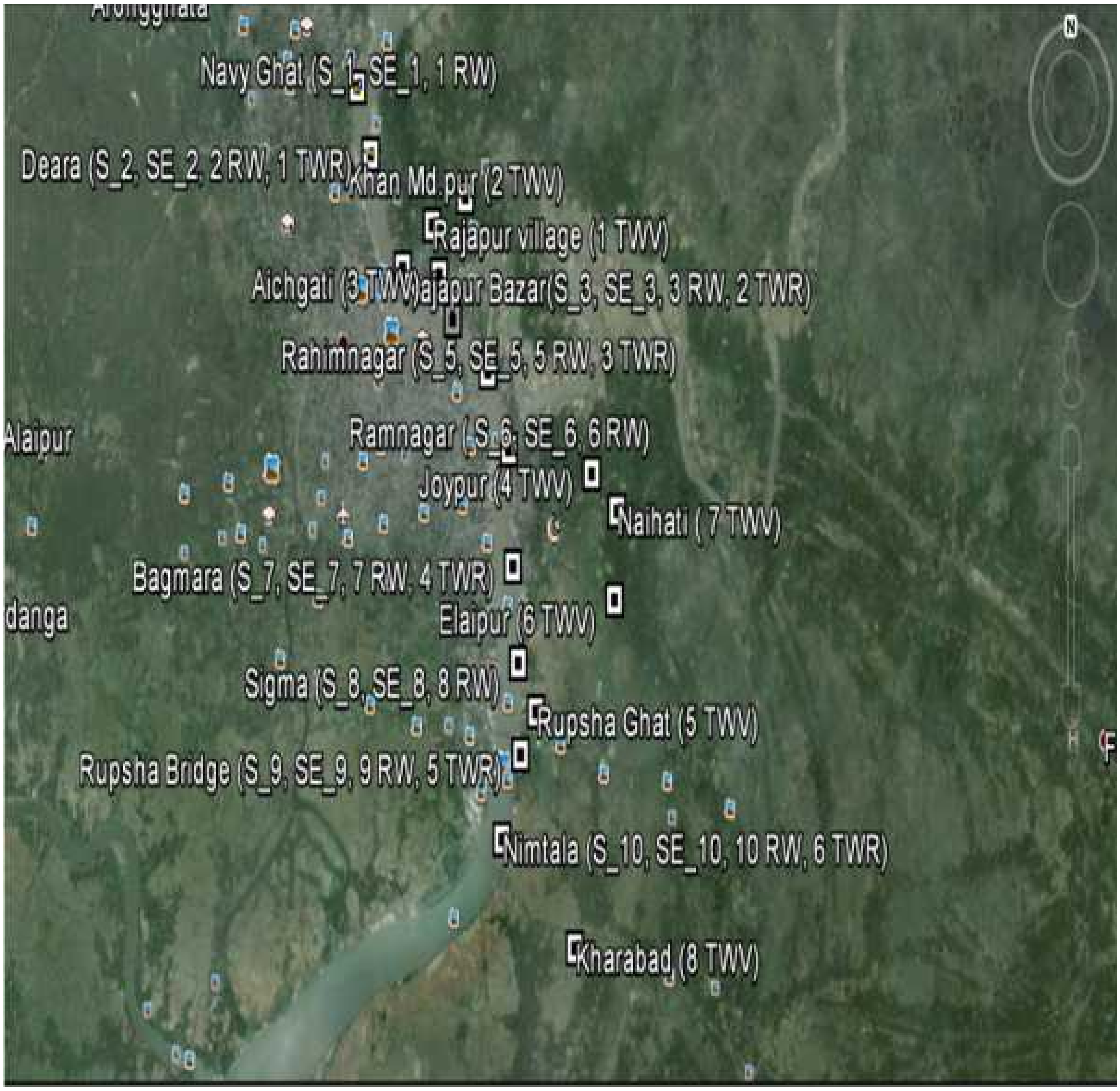

Fig 3.2: Location map of sampling (using Google map) at the Rupsha River area, Khulna, Bangladesh

Processing of Solid Samples

After the collection of soil and sediment samples, all samples were brought to the sample preparation room at the Health Physics and Radioactive Waste Management Unit, INST, AERE, Savar, Dhaka. The samples were then cleaned for stones, gravels, grass-roots, vegetation etc. and then dried in the sun for several days and crushed into fine powder by using a grinder and collected after passing through 400 µm mesh screen. The homogenized samples were then dried in an oven at about 100˚C for about 24 hours. The homogenized samples were then transferred to sealable cylindrical plastic containers of 7 cm height and 5.5 cm in diameter and the weights (after grinding) of the samples were recorded using an electrical balance. The sample-filled plastic containers were sealed tightly with cap and wrapped with thick vinyl tape around their necks; marked individually with identification number, sample location, date of preparation and net weight and then stored for about 30 days to assume secular equilibrium between ^{226}Ra and ^{232}Th series and their daughter progenies. Fig 3.3 shows that the solid samples preparing steps.

Table 3.1: Detailed of the collected samples for study (with location- local name)

Sample type	Sample ID	Location	Date of collection	Date of preparation	Net weight of sample
Soil	S_1	Navy ghat, Port area	30.04.2015	17.05.2015	180.23 gm
	S_2	Deara, Paul parha	30.04.2015	17.05.2015	193.25 gm
	S_3	Rajapur Bazar	30.04.2015	17.05.2015	234.76 gm
	S_4	Singer chor	30.04.2015	17.05.2015	208.54 gm
	S_5	Rahimnagar	30.04.2015	17.05.2015	163.85 gm
	S_6	Ramnagar	30.04.2015	17.05.2015	199.43 gm
	S_7	Bagmara, Chor Rupsha	30.04.2015	18.05.2015	209.60 gm
	S_8	Sigma, Chor Rupsha	30.04.2015	18.05.2015	181.71 gm
	S_9	Rupsha Bridge	30.04.2015	18.05.2015	201.05 gm
	S_10	Nimtala	30.04.2015	18.05.2015	254.79 gm
Sediment	SE_1	Navy ghat, Port area	30.04.2015	20.05.2015	189.22 gm
	SE_2	Deara, Paul parha	30.04.2015	20.05.2015	189.08 gm
	SE_3	Rajapur Bazar	30.04.2015	20.05.2015	226.89 gm
	SE_4	Singer chor	30.04.2015	20.05.2015	192.89 gm
	SE_5	Rahimnagar	30.04.2015	20.05.2015	211.62 gm
	SE_6	Ramnagar	30.04.2015	20.05.2015	197.30 gm
	SE_7	Bagmara, Chor Rupsha	30.04.2015	21.05.2015	187.64 gm
	SE_8	Sigma, Chor Rupsha	30.04.2015	21.05.2015	200.17 gm
	SE_9	Rupsha Bridge	30.04.2015	21.05.2015	201.67 gm
	SE_10	Nimtala	30.04.2015	21.05.2015	267.08 gm

Sample type	Sample ID	Location	Date of collection	Date of preparation	Net weight of sample
Surface water (River water)	1 RW	Navy ghat, Port area	30.04.2015	13.05.2015	270.16 ml
	2 RW	Deara, Paul parha	30.04.2015	13.05.2015	267.53 ml
	3 RW	Rajapur Bazar	30.04.2015	13.05.2015	272.90 ml
	4 RW	Singer chor	30.04.2015	13.05.2015	267.17 ml
	5 RW	Rahimnagar	30.04.2015	13.05.2015	268.52 ml
	6 RW	Ramnagar	30.04.2015	13.05.2015	268.67 ml
	7 RW	Bagmara, Chor Rupsha	30.04.2015	13.05.2015	276.31 ml
	8 RW	Sigma, Chor Rupsha	30.04.2015	13.05.2015	270.89 ml
	9 RW	Rupsha Bridge	30.04.2015	13.05.2015	268.19 ml
	10 RW	Nimtala	30.04.2015	13.05.2015	268.52 ml
Drinking water (Tube well water) TWR- River side tube well water TWV- Village tube well water	1 TWR	Deara, Paul parha	30.04.2015	13.05.2015	267.71 ml
	2 TWR	Rajapur Bazar	30.04.2015	13.05.2015	263.76 ml
	3 TWR	Rahimnagar	30.04.2015	13.05.2015	262.79 ml
	4 TWR	Bagmara, Chor Rupsha	30.04.2015	13.05.2015	266.10 ml
	5 TWR	Rupsha Bridge	30.04.2015	13.05.2015	266.21 ml
	6 TWR	Nimtala	30.04.2015	13.05.2015	266.27 ml
	1 TWV	Rajapur village	01.05.2015	13.05.2015	265.89 ml
	2 TWV	Khan Mohammadpur	01.05.2015	13.05.2015	265.32 ml
	3 TWV	Aichgati	01.05.2015	13.05.2015	265.05 ml
	4 TWV	Joypur	01.05.2015	13.05.2015	265.86 ml
	5 TWV	Rupsha ghat	02.05.2015	13.05.2015	265.65 ml
	6 TWV	Elahipur	02.05.2015	13.05.2015	267.55 ml
	7 TWV	Noeihaty	02.05.2015	13.05.2015	267 ml
	8 TWV	Kharabad	02.05.2015	13.05.2015	265.92 ml

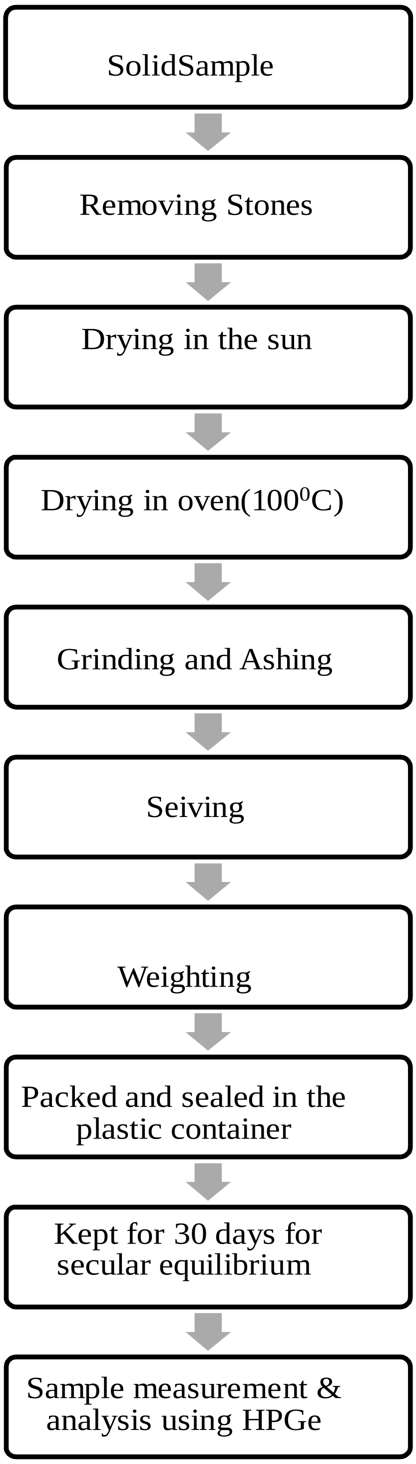

Fig3.3: Flow-chart illustrating the pre-treatment of solid samples

Processing of Liquid Samples

Cylindrical type beakers (0.5 litre capacity) were used to process and measure the water samples. At the start of the sample processing steps, the beakers were made contamination free by cleaning those well using light hydrochloric acid solution and de-ionized water. The beakers were then dried using a temperature-controlled oven. After measuring the sample (260 ml), samples were then transferred to sealable cylindrical plastic containers of 8 cm height and 6.5 cm in diameter. The weights of the samples were determined from the difference of weights of sample-filled and empty container. Finally, the containers filled with samples were closed by caps, wrapped with thick vinyl tape around their necks and kept for 30 days for achieving the secular equilibrium between gaseous and non-gaseous decay products of naturally occurring radionuclide series. The radiometric measurements these samples were also done at the Health Physics & Radioactive Waste Management Unit, INST, AERE, Savar, Dhaka.

3.5 Experimental Set up

A general description of the radionuclide detection technique for soil, sediment and water samples are given below, including the description of detector and the calibration process of the gamma spectrometry system. The experimental layout and treatments used are then outlined and finally the analytical methods used for the analysis of all soil, sediment and water samples are described.

Radionuclide Detection Technique of Radioactive Samples

A number of analysis systems exists which are able to determine the activity and radionuclide content of various types of samples and geometry. For all types of samples, gamma spectrometry is generally the most effective technique to analyze the gamma emitting radionuclides in these samples. The method is highly suited for accurate multi-nuclide analysis without any chemical separation for environmental materials. The system is now widely used by laboratories, which are dealing with the analysis of gamma emitting radionuclides in environmental samples. The detection of radionuclides and its activity can be done using chemical separation methods, however, the method is costly and time consuming. On the other hand, gamma spectrometry is not expensive but some preliminary work (such, an energy calibration and self absorption and efficiency calibration) must be undertaken before using the system for the analysis of multi-nuclides in contaminated.

First, an energy calibration has to be performed. The sample for this must contain various radionuclides, which have a good spread of ¥ -energies i.e., the energies must range from the detectable minimum up to the detectable maximum. This produces a much more accurate calibration. Secondly, in order to measure the activity of a sample, it is necessary to know the system's detection efficiency, which is obtained by employing known standard sources. The calibration standard source must have physical dimensions, chemical composition and density similar to the samples that will be analyzed, so that the deviation in the measured activity is normalized. However, it is necessary to subtract background counts from the standard source counts to measure the accurate count rates of standard samples (Debertin and Helmer, 1988; Koddis *et al*.). The two most important gamma analysis detectors that are available presently are sodium iodide crystal detectors (NaI) and liquid nitrogen cooled high purity germanium detectors (HPGe). HPGe detectors, due to their excellent resolution have become an important tool for the analysis of radioactive samples using gamma-ray spectrometric techniques. The absolute efficiency response of these detectors is an important parameter for almost all work based on absolute method. A high purity germanium detector is widely used to determine quantitatively the concentrations of radionuclides in the radioactive waste samples. A brief description of an HPGe detector is given in the following section.

3.6 Apparatus Used

High Purity Germanium (HPGe) Detector

Now-a-days HPGe detector is extensively used for gamma ray spectrometry. The world-wide popularity of germanium as semiconductor radiation detector is attributable to the excellent charge transport properties, which allows the use of large crystals without excessive carrier losses due to trapping or recombination. The greater efficiency, large photo fraction and lower cost of sodium iodide may well tip the balance in its favor when only a few gamma ray energies are involved. Germanium detectors are clearly preferred for the analysis of complex gamma ray spectra involving many energies and peaks, it also aids in the detection of weak sources of discrete energies when superimposed on a broad continuum.

Germanium detectors are semiconductor diodes having a p-I-n structure in which the intrinsic region is sensitive to ionizing radiation, particularly X-rays and gamma rays. Under reverse bias, an electric field extends across the intrinsic or depleted region. When photons interact with the material within the depleted volume of a detector, charge carriers (holes and electrons) are produced and are swept over by the electric field to the p and n electrodes.

This charge, which is in proportion to the energy deposited in the detector by the incoming photon, is converted into the voltage pulse by an integral charge sensitive preamplifier (Canberra Product Catalog; Roy, 1991).

HPGe detectors are available in two relatively simple geometries:

a. The planer detector in which the electric field is fairly uniform and

b. The co-axial configuration in which the electric field varies inversely with the radial distance from the detector axis.

The gamma ray detection efficiency and response function for the HPGe detector are identical to those observed in a Ge(Li) detector of the same size and shape.

A p-type co-axial HPGe detector of volume 93 cm^3 supplied by CANBERRA Model No. GC-2018 and serial No. 04089411 has been used in the present experiment at the Health Physics and Radioactive Waste Management Unit (HPRWMU) Laboratory, Institute of Nuclear Science and Technology (INST), Atomic Energy Research Establishment (AERE), Savar, Dhaka. The HPGe detector used is co-axial geometry type with electrical contacts in the form of concentric cylinders closed at the end. This geometry makes it possible to produce very large volume detector elements with excellent efficiencies for high-energy photons. Thus the HPGe detector is basically a cylinder of germanium with an n+-type contact on the outer surface and a p+-type contact on the surface of the axial wall. The n+-type contact is formed by evaporation of lithium into a lapped surface of germanium and p+-type contact consists of a metal to semiconductor surface barrier junction. These results are an n+-p-p+ configuration of the detector in which the depletion region formed by reverse biasing requires that a positive voltage is to be applied to the n+ contact with respect to p +surface. The depletion effectively begins at the n+ edge of the central region and extends further into the p region as the voltage is raised. Since there is a significant dead layer on the n+ face, the p+ face is normally used as the entrance window. Ion implantation techniques are also used to form the p+ contact especially when very thin entrance window is needed.

The main characteristics of the HPGe detector are high atomic number, low impurity concentration, i.e., large deletion depth, lowest ionizing energy required to produce an electron hole pair, higher conductivity, compact size, fast time response, high resolution and relative simplicity of operation at room temperature.

The main parts of this detector coupled with other accessories are:

(1) Liquid nitrogen (LN_2),

(2) Cryostat,

(3) Digital Spectrum Analyzer (DSA) 1000
    i. A preamplifier,
    ii. Spectroscopy amplifier,
    iii. High voltage detector power supply,
    iv. Multi channel analyzer (MCA),
(4) Shielding arrangement of the detector and
(5) Computer

The block diagram of HPGe detector with its accessories and a photograph of this set-up are shown in Fig 3.4 and Fig 3.5 respectively. Brief descriptions of these parts are given below.

(1) Liquid Nitrogen (LN_2) Dewar

Germanium has relatively low band gap, these detectors must be cooled in order to reduce the thermal generation of charge carriers (thus reverse leakage current) to an acceptable level. Otherwise, leakage current introduced noise destroys the energy resolution of the detector. Liquid nitrogen (LN_2), which has temperature of 77 ^{0} K is the common cooling medium for such detectors. The detector is mounted in a vacuum chamber, which is attached to or inserted into an LN_2 Dewar. The sensitive detector surfaces are thus protected from moisture and condensable contaminants (PGT HPGe Detector Operating Manual). The liquid nitrogen Dewar serves as reservoir of liquid nitrogen, while the cryostat provides a path via the cooper steam for heat transfer from the detector to nitrogen reservoir.

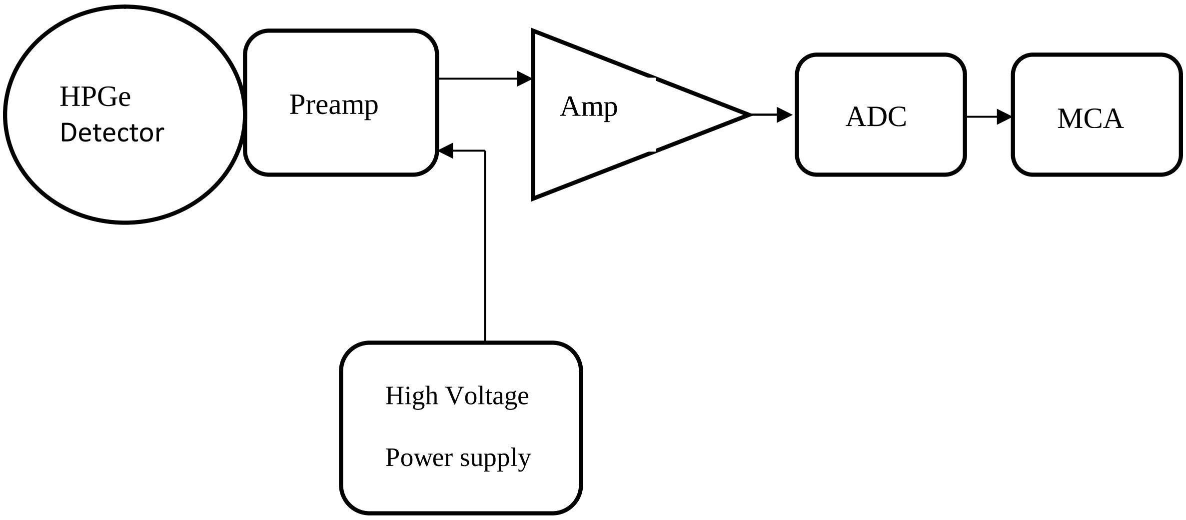

Fig. 3.4: Block diagram of gamma spectroscopy system (HPGe detector) used in the present work.

Fig 3.5: A complete setup of γ-counting system (HPGe Detector with 20% relative efficiency).

(2) Cryostat

A cryostat consists of a vacuum chamber which houses the detector element plus a Dewar (double wall vacuum-insulated vessel) for the liquid nitrogen cryogen. Integral cryostats have a common vacuum chamber for the Dewar and detector. Unlike the dipstick type, the detector chamber and Dewar cannot be separated without breaking vacuum. A basic integral cryostat is shown in Fig 3.6. The cryostat is a sealed vacuum chamber and usually the vacuum is maintained by a passive system, a molecular sieve and placed in the bottom of the cold finger assembly. This molecular sieve absorbs any gaseous molecules, which can lose inside the cryostat and prevents them from depositing on the surface of the cryostat. Otherwise, the increasing surface contamination on the crystal would result in increased surface currents, which, in turn, elevates the noise and broadens the resolution (Roy, 1991).

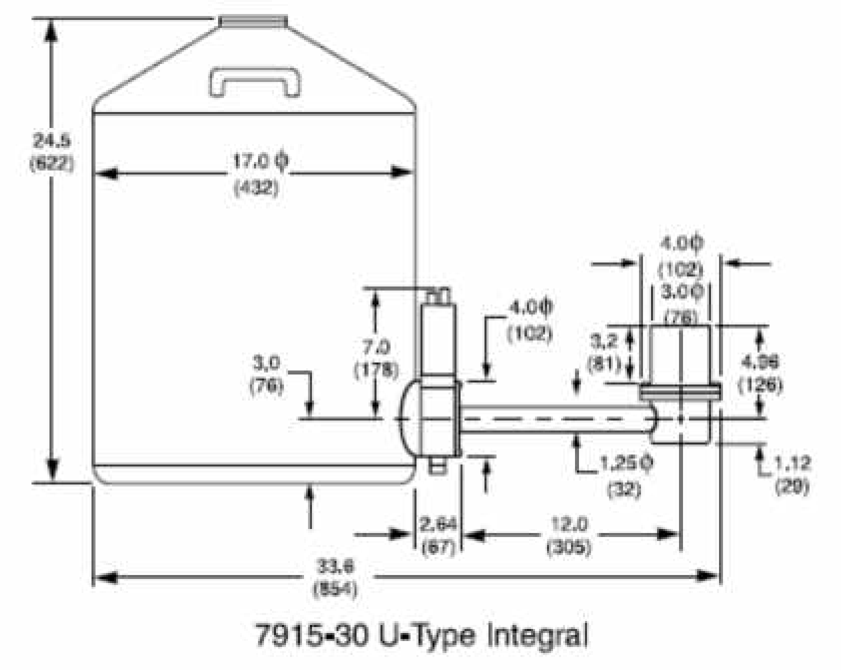

Fig 3.6: Photograph of Cryostat

(3) Digital Spectrum Analyzer (DSA) 1000

The DSA-1000 is a full featured 16K channel integrated Multichannel Analyzer based on advanced digital signal processing techniques (DSP). When paired with the computer of choice, the DSA-1000 becomes a complete spectroscopy workstation, capable of highest quality acquisition and analysis. Fig. 3.7 shows the Digital Spectrum Analyzer.

Fig 3.7: Digital Spectrum Analyzer (DSA) 1000

The main components are given below:

i. Preamplifier (Model 2002 CSL)

The preamplifier associated with radiation detectors performs three essential functions:

a. Conversion of charge to voltage pulse
b. Signal amplification
c. Pulse shaping.

Most preamplifiers in use today are charge sensitive and provide an output pulse with amplitude proportional to the integrated charge output from the detector. General-purpose preamplifiers have a RC feedback network (Fig 3.8) which results in a quasi-step function output. For extremely low noise, the feedback resistor is eliminated and the output signal becomes a true step function, which builds in random staircase fashion and is reset by so called pulsed-optical feedback circuitry. For many high count rate and high resolution applications with HPGe detectors, the transistor reset preamplifier (TRP) offers the best performance.

There are two basic types of preamplifiers used in germanium detectors:

(a) Charge sensitive that employs either dynamic charge restoration (RC feedback),

(b) Pulse charge restores type (pulse optical or transistor reset) for discharging the integrator.

Absorption of photon by detector produces a current pulse at the preamplifier input. These pulses are too small to measure without amplification into a measurable electric signal. Therefore, the first element in a signal processing chain is a preamplifier that provides interference between the detector and pulse processing and analyzing electronics. The preamplifier has been located as close as possible to the detector to minimize the signal from noise and captive loading. It also serves as an impedance matcher, presenting high impedance to the detector to minimize loading, while providing a low impedance output to drive succeeding components. Canberra Model 2002 CSL used in the present work has the following characteristics.

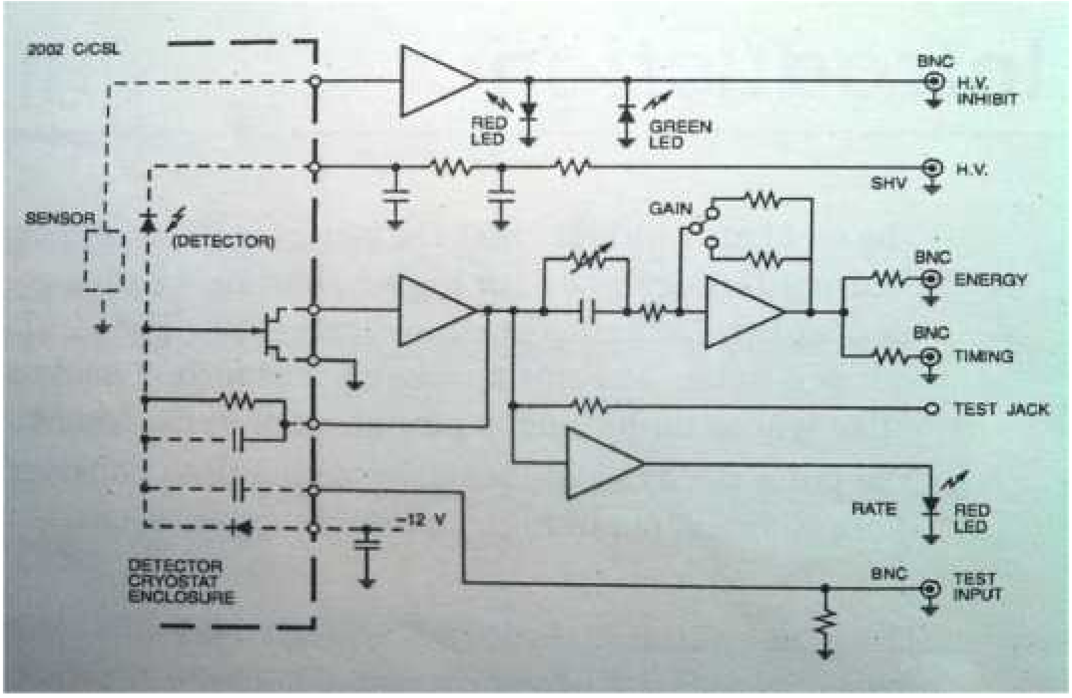

Fig 3.8: Block diagram of preamplifier

Characteristics of Model 2002C Preamplifier:

Noise : < 500 eV.
Charge or energy sensitivity : 100 or 500 mV/MeV (Ge).
Charge or energy rate capability : 2×10^5 MeV/sec.
Rise time : < 50 ns.
Bias rating : 5000

ii. Amplifier

Accepts positive or negative signals from an associated detector preamplifier; amplitude for full scale conversion ±10 V divided by selected gain; maximum input (signal +dc) for linear operation is dependent on the Input Attenuator setting; Attenuator OFF (x1): ±4 V, Attenuator ON (x 0.25): ±12 V, dc coupled and protected to ±24 V maximum; rise time: less than the selected Rise Time + Flat Top settings; acceptable preamplifier decay time constant: 45 μs to infinity; Zin is 1.3 kΩ; rear panel BNC connector.

iii. High Voltage Power Supply

Dual range and polarity high voltage power supply; voltage range and polarity selected by programming modules: ±10 to ±1300 V dc or ±1300 to ±5000 V dc; rear panel SHV connector. Low end of the 5000 V range is limited to 1300 V by software.

iv. Multi Channel Analyzer (MCA)

MCA is capable of analyzing pulses simultaneously with many different intervals or channels. In fact, MCA’s are heart of most modern experimental measurements. It’s essential functions are collection of data providing a visual monitor and producing output either in the form of final results or as raw data for later analysis. The MCA consists of an analog-to-digital converter (ADC), MCA buffer and a display. The main component of the MCA is an analog-to-digital converter (ADC), which converts the incoming analog amplifier signal to a group of standard shaped pulses. The pulses are digitized by a Wilkinson type analog-to-digital converter (ADC) and the output pulses are stored in a computer type memory (Wilkinson, 1950). The channel number is the memory address and is proportional to the input signal voltage. Therefore, pulses of constant amplitude will always be stored in a signal channel. Each pulse is digitized and a count is added to the appropriate memory location. So the ADC is the key element in determining the performance characteristics of the analyzer.

(4) Shielding Arrangement

The shielding of the detector from the environmental radiation is an absolute necessity for low-level measurement of activity. The shielding arrangement surrounding the detector has been designed and fabricated by using lead and steel material, available in local market. Because of high density (11.4 gm/cc) and large atomic number ($Z = 82$) of lead, it is widely used for the construction of radiation shielding. Hard gamma rays from external background source (such as 1.46 MeV from ^{40}K) can be absorbed efficiently by lead. Moreover, it is reasonably effective for removing many of the cosmic ray components of the background radiation. The photoelectric absorption of gamma rays in the lead shielding around the detector can lead to the generation of characteristic X-ray, which is covered by steel. Steel has much lower atomic number (34) compared to that of lead. A photograph of the shielding arrangement of the Detector is shown in Fig 3.9.

Fig 3.9: Photograph of the Shielding Arrangement of the Detector

The Shielding expression is

$$I = I_0 e^{-\text{«} t} \quad (3.1)$$

Where I is the beam intensity after penetrating a thickness t of the material, « is the linear attenuation coefficient of absorbing material and I_0 is the intensity when thickness $t = 0$. Theoretically, the shielding arrangement was found to attenuate 95%-99.99% of unwanted gamma flux of energy ranging from 303 KeV to 1332 KeV, where most of the gamma lines from background radiation (Thorium, Uranium, and Actinium series) were found to decrease by 74% to 96%(Roy, 1991). The shielding material around the detector (lead rings) has the characteristics given below:

Table 3.2: Characteristics of the shielding material used around the detector

Shielding Lead Ring:

a. Internal diameter : 305 mm
b. External diameter : 406 mm
c. Wall thickness : 51mm
d. Shielding height : 559 mm

Double Part, Top Opening & Sliding Load Door:

a. External Diameter : 406 mm

b. Thickness : 51 mm

Base Plate (Lead & MS)

a. External Diameter : 406 mm

b. Thickness : 51 mm
c. Thickness of the Bottom of
Base Plate (MS Plate) : 10 mm

Table /platform:

a. Height : 3048 mm

b. Size : 1219.2x 609.6mm^2
(Made of 51x 51 mm^2 Ms Box, 3mm MS plat, 457x 457 mm^2 support box)

Replacement Arrangement:

a. Height : 3048 mm

b. Size : 1219.2 x 609.6mm^2
(Materials 51x51 mm^2 MS box, 3mm MS plat)

(5) Computer

The energy spectrum of the radiation was observed in computer. The configuration of the computer is shown below:

Processor : Intel(R) Pentium(R) 4
RAM : 504 MB
Monitor : CRT (cathode ray tube)
Operating System used : Microsoft window XP professional
Software used : version 2002 service pack 2

As a whole, the following are the specifications of the HPGe detector (Model GC 2018):

Detector : HPGe
Detector model : GC 2018
Serial number : 04089411
Crystal geometry : closed-end coaxial
Crystal diameter : 6.2 cm
Crystal length : 3.1 cm
Crystal active volume : 93 cm^3
Crystal / Window distance : 0.5 cm
Dewar capacity : 30 liter
Cooling temperature of
The Ge Crystal : 77^0 K (i.e., LN_2 temperature)
Energy resolution of the detector
(FWHM at 1332 KeV of ^{60}C
Gamma rays) : 2 KeV (specified by manufacturer)
Relative Efficiency : 20 %
Peak to Compton ratio : 50: 1

Standard Geometry Setup

For the measurement of radionuclide in investigated sample such as soil, sediment and water samples, a standard geometry is needed which is similar to the geometry of calibration standard. In this experiment, 260 ml cylindrical geometry was chosen for the measurement of liquid samples. For solid samples, 3.75cm × 8.5cm plastic container was used to measure the radionuclides activity. To measure the radionuclide of the sample, the liquid and solid samples were transferred to the plastic container and then placed on the top of the detector.

Some of the standard geometry (plastic container) with experimental samples is shown in Fig 3.10, Fig 3.11 and Fig 3.12.

Fig 3.10: Soil samples in individual plastic container

Fig 3.11: Sediment or sand samples in individual plastic container

Fig 3.12: Water samples in individual plastic container

Standard ¥- Ray Sources

Gamma ray reference point sources are essential in any laboratory to calibrate the γ-spectrometer for the measurement purposes. The calibration sources available in the Health Physics and Radioactive Waste Management Unite (HP&RWMU), Institute of Nuclear Science & Technology (INST), AERE, Savar, Dhaka, were all supplied by Amershem International, USA. Their physical characteristics are listed in Table 3.3.

The activity of a source at any time from the day of its initial activity A_o can be calculated by using the radioactive decay equation as

$$A_t = A_o e^{\frac{-0.693 \times t}{t_{1/2}}} \quad (3.2)$$

Where, A_o is the initial activity of the standard source at $t = 0$, A_t is the activity of the source after time t and $t_{1/2}$ is the half- life of source.

Table 3.3**:** Physical characteristics of ^{137}Cs and ^{60}Co radionuclide

Radio nuclides	Half time (Year)	Energy E in KeV	Intensity (Iγ)
^{137}Cs	30	661.62	0.8521
^{60}Co	5.27	1173.2	0.9990
		1332.5	0.9998

3.7 Calibration of the Detector Parameters

In the gamma spectrometry the spectra accumulated on the computer based Multi Channel analyzer (MCA) provides data on both count rate and the location of each peak depending on gamma energy. In order to convert these data onto either emission rate or energy, the spectrometer should be calibrated with gamma sources of known energy. For this purpose details information on the following parameters are necessary.

a. Energy calibration of MCA
b. Counting Efficiency Calibration
c. Lower limits of detection
d. Background spectrum

Energy Calibration

In gamma spectrometry, radiation pulses are recorded by a multi-channel analyzer (MCA) and the location of the peak depends on the gamma ray energy. For identifying a particular radionuclide of unknown sample, it is necessary to calibrate the MCA by observed γ-ray energy spectrum against the channel number. The displayed spectrum from a HPGe detector is usually a series of photo peaks superimposed on a more or less varying background. The peak location indicates gamma ray energy. The value of the baseline, i.e., channel number has no real significance until it can be calibrated proportionally to read in terms of energy.

For HPGe detector the relation between gamma energy and output pulse height is nearly linear. Therefore, two or more known peaks of sufficiently different energy will serve to establish the energy calibration, Let E_1 and E_2 are the known energies of peaks and let X_1 and X_2 are the peak locations measured in the pulse height spectrum. Thus, energy per channel can be calculated as:

$$E = mX + b \qquad (3.3)$$

Where X is any channel number, energy per channel (m) = $(E_2-E_1)/(X_2-X_1)$,

Constant (b) = E_1-mX_1Thus $X = (E-b)/m$

In the present study calibration of the MCA was carried out by using good geometry point sources placed close to the detector inside the shield. The gamma spectra obtained on the MCA monitor after the equipment set up of live time, high voltage power supply (4500 Volts), adjustment of spectroscopy amplifier such as course gain (50), fine gain (0.8), shaping time (2µsec). The energies of the calibration source in keV were entered in the MCA to convert all 16384 channels to respective energies. The following Table 3.4 gives a list of calibration source and their energies.

Table 3.4: Gamma ray energy calibration sources

Source	Energy in keV	Emission Probability	Half Life In years
^{137}Cs	661.66	85.20	30.17
^{60}Co	1173.2	99.89	5.272
	1332.5	99.98	5.272

Lower Limit of Detection (LLD) of Radionuclides

The detection limit, as it is known as minimum detectable emission rate or lower limit of detection (LLD) is a term used to express the detection capability of a measurement system under certain conditions. The limit depends on the sample geometry, the energy of the radiation, the source-detector distance, the detector efficiency, the background, the available time for measurement and the quantity of samples (mass and volume). In a measurement if the measured number of counts, N in the time T is large, then number of background counts N_b , in the same interval T must be known from a measurement without the sample. The statistical fluctuation of N_b can be described by the standard deviation S (N_b)= $\sqrt{N_b}$ provided N_b was taken in the same interval T as N. If the number of additional counts due to photons from the sample, N_s = N- N_b is of the order of background fluctuations, i.e. of S(N_b) then there is no clear evidence of the existence of a sample effect. On the other hand, if N_s is, say larger than 3 S(N_b), the probability of the presence of a sample effect is rather high. Therefore, the detector limit can be given as L = 3 $\sqrt{N_b}$. The lower limit of detection (LLD) at the 95% confidence level has been defined by Pasternak as: LLD = $1.645\left(2\sqrt{2}\right)S_b$, where S_b is the standard deviation of the background. The standard deviation of the distribution is the square root of the mean value for a particular sampling interval; the S.D. is the observed number of counts $n \sqrt{n}$. The standard deviation associated with a count rate is S= $\sqrt{n}/t$. The S.D. of the sum or difference of two measurements is the square root of the sum of the squares of the standard deviations associated with the measurements. The standard deviations of the net count rate obtained is

$$S_n = \sqrt{(S_g + S_b)}$$

$$= [n_g / t_g^2 + n_b / t_b^2]^{1/2} \qquad (3.11)$$

The lower limit of detection for the counting portion of the analysis is:

$$\text{LLD} = 1.65(2\sqrt{2})\, S_b$$

$$= 4.653\, [n_b / t_b^2]^{1/2} \qquad (3.12)$$

For the calculation of the lower limit of detection of food and environmental samples the following equation was used:

$$\text{LLD} = \frac{4.653 \times S_b}{E \times I \times V} \qquad (3.13)$$

Where S_b is the standard deviation in the region of interest, E is the counting efficiency, I is the intensity of gamma energy and V is the sample in liter. Counting efficiency E is different for different gamma energies and counting geometries.

When S_b is $3\pm$ then,

$$\text{LLD} = \frac{4.653 \times 3\pm}{E \times I \times V}$$

$$= \frac{4.653 \times 3}{E \times I \times V} [n_b / t_b^2]^{1/2} \qquad (3.14)$$

Where n_b is the background count and t_b is the background time.

$$\text{S.D} (\pm\pm) = [n_g / t_g^2 + n_b / t_b^2]^{1/2} = X \text{ cps}$$

For activity calculation,

$$\text{S.D} (\pm\pm) = \frac{X \text{ cps} \times 100}{\% E \times I \times W \text{ (in Kg)}} \qquad \text{Bq.Kg}^{-1} (3.15)$$

Where n_g is the gross count and t_g is the counting time with sample. The LLD of different gamma energy regions for 150gm samples of geometry size rad.4.9× ht.7.0 was used in the present work; the counting times were 10000 seconds. The results have been given in Table 3.5.

Table 3.5: Detection limits of the HPGe detector

Radionuclides	Detection limits of HPGe detector
^{214}Pb	0.0466
^{214}Pb	0.0308
^{208}Tl	0.0393
^{208}Tl	0.0067
^{214}Bi	0.0137
^{228}Ac	0.0244
^{228}Ac	0.0390
^{214}Bi	0.0433
^{40}K	0.1311

Statistical Error in Counting

In gamma ray spectrometry the quantity of interest, like the activity of a source or the energy of gamma ray are derived from other measured quantities by a mathematical relationship. The radioactive decay is random in time and so the number of particles of photons counted in a given time will fluctuate about an average value. The standard deviation σ is a measure of the scatter of a set of observations about their average value. The most common method of analysis gamma-spectrum of samples containing a mixture of nuclides is to use the full energy peak counts of various isotopes for estimating activities because the full energy peak is a characteristic of the isotopes it is in this energy region that a better sample to background counts is obtained.

Sometimes the constituent nuclides emit gamma rays of closely spaced energies, from which a small portion of the full energy peak of each of them are selected. This reduces the region of mutual overlap of adjacent peaks, thereby improving source counts to background ratio for each of the radionuclides. To minimize the statistical error if an isotope emits more than one gamma ray, the most abundant gamma energy should be taken for analysis. If there are several gamma energies comparable abundance, the highest energy that is likely to have least Compton contribution from other nuclides should be selected.

Since the nuclei undergoing radioactive transformation in a sample is random event occurring in a few of atoms, the Poisson distribution may be applied and errors in the recorded counts are usually expressed as the standard deviation that is simply the square root of the number of counts. One standard deviation implies that 68.3% result lies within this range.

The counting error can be reduced by increasing

(1) Counting efficiency,

(2) Volume and

(3) Counting time.

Additionally, the background of counts of the detector will also increase counting accuracy. For count of N in time ‘t’ the standard deviation= $\sqrt{N}$

$$\frac{N}{t} = [RT]^{1/2}/t = [RT]^{1/2} = \left[\frac{N}{t^2}\right]^{1/2} \tag{3.16}$$

The standard deviation of the net counting rate is

$$\sigma_s = \left(\sigma_g + \sigma_{bg}\right)^{\frac{1}{2}} = \left[\frac{r_g}{t_g} + \frac{r_{bg}}{t_{bg}}\right]^{1/2} \tag{3.17}$$

Where, σ_g =standard deviation of gross counting rate

σ_b =Standard deviation of background counting rate,

r_g=Gross counting rate,

r_b =Background counting rate,

t_g=time during which gross counting was made,

t_b =time during which background count was made.

Percent of error= $\frac{\sigma}{A} \times 100$ (3.18)

Where A = The activity of the sample. In present work, 2σ counting error has been taken for the calculation of activity measurement.

Prepared Standard Source efficiency results

An efficiency curve was obtained for standard using the 8 experimental points available. The results of measured peak efficiencies for the standard geometry of 400 ml are shown in Table-3.6. The HPGe detector efficiencies have been measured with uncertainties between 5-7%. The values of the function parameters were determined by regression analysis. The experimentally measured data cover 80-3000 KeV range for this geometry. The chi-square results show the establishment of the satisfactory response curves in the 180 to 3000 KeV ranges. The intensities for the corresponding gamma ray energies were taken from IAEA guide book (IAEA, 1989).

Table 3.6: Counting efficiencies of the HPGe detector used for activity calculation

Radionuclides	Peak energy (KeV)	Intensity, I	Efficiency (%)
^{212}Pb	238	0.435	0.041105157
^{214}Pb	295	0.1815	0.034304887
^{214}Pb	351	0.351	0.029632951
^{208}Tl	583	0.307	0.019327001
^{214}Bi	609	0.446	0.018629617
^{228}Ac	911	0.266	0.013270423
^{228}Ac	969	0.1623	0.012598144
^{214}Bi	1120	0.147	0.011151435
^{40}K	1460	0.107	0.00891975
^{214}Bi	1764	0.151	0.007606088
^{208}Tl	2613	0.356	0.005462992

3.8 Measurement Set-up

The detection and measurement of radionuclides in the samples were carried out by gamma spectrometry system using a vertical coaxial cylindrical high purity germanium (HPGe) detector of 93 cm^3 active volume and with 20% relative efficiency. The p-type HPGe detector supplied by CANBERRA, Model- GC-2018 (Canberra Product Catalog), had a resolution of 1.8 KeV at 1332 KeV of Cobalt-60 gamma-ray lines. The detector was coupled to a 16 k-channel analyser. The samples was placed on the top of the detector inside the shielding arrangement and counted for 10,000 seconds after adjustment of the necessary parameters such as resolution, peak to Compton ratio etc. And after determination of minimum detectable activity of the detectors the spectra of all samples were perfectly analysed using Genie-2000 spectra analysis software (which matched various gamma energy peaks to a library of all possible radionuclides) to calculate the concentrations of ^{238}U, ^{232}Th and ^{40}K. The detector was enclosed in a cylindrical shielding container made of lead and iron with 51 mm thickness, 559 mm height and 305 mm internal diameter and having a fixed bottom and moving cover to reduce the external gamma-ray background (Islam, 2009). All the samples were counted for 10 ks. Prior to the measurement of the samples, the environmental gamma background at laboratory site was determined with an identical empty plastic container used in the sample measurement. The energy regions selected for the corresponding radionuclides were 295 KeV and 352 KeV of ^{214}Pband 609 KeV and 1120 KeV of^{214}Bi for^{226}Ra, 238 KeV of ^{212}Pb, 583 KeV of ^{208}Tl, 911 KeV and 969 KeV of ^{228}Ac for ^{232}Th and 1460 KeV for ^{40}K (Roessier *et al.*, 1970).

3.9 Calibration of the Detector

The efficiency calibration of the detector was performed by standard sources of solid and liquid matrixes prepared using Ra-226 standard using identical containers used for the measurement of the samples, e.g., 180 ml plastic container. The preparation process of standard sources had been reported elsewhere (Harb *et al.*, 2008).The detector efficiency calibration curves as a function energy for both solid and liquid matrixes are shown in Figure 3.13(a) and Figure 3.13(b). The energy calibration of the detector was performed by ^{137}Cs and Cobalt-60 point sources.

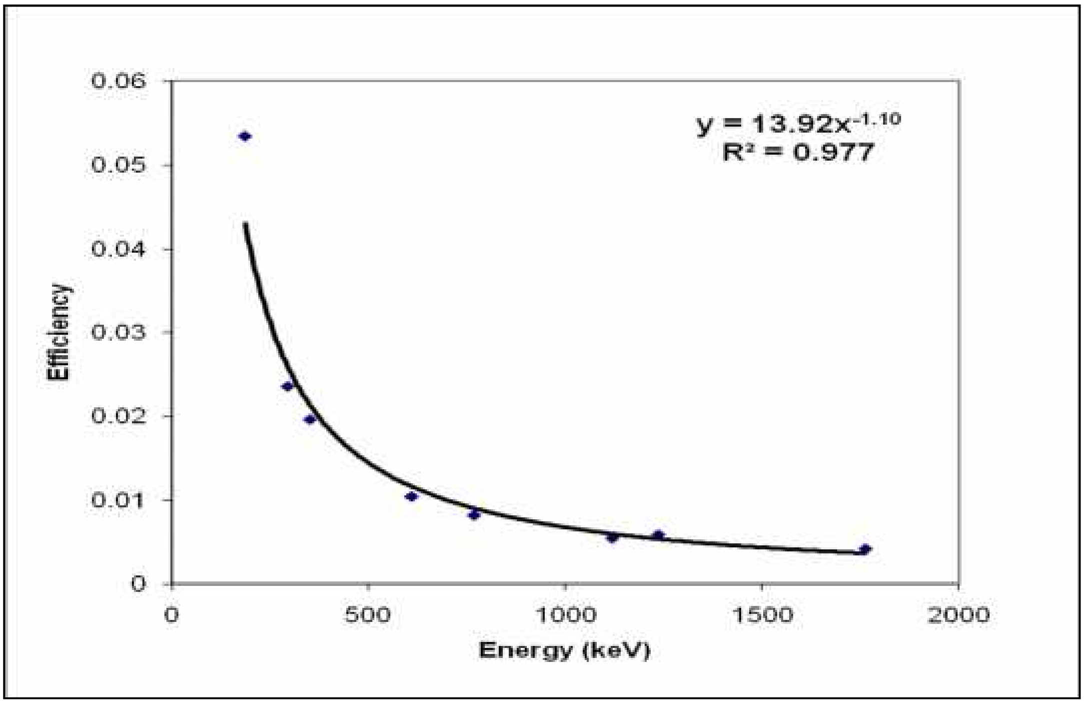

Fig 3.13(a): Efficiency curve for solid matrix

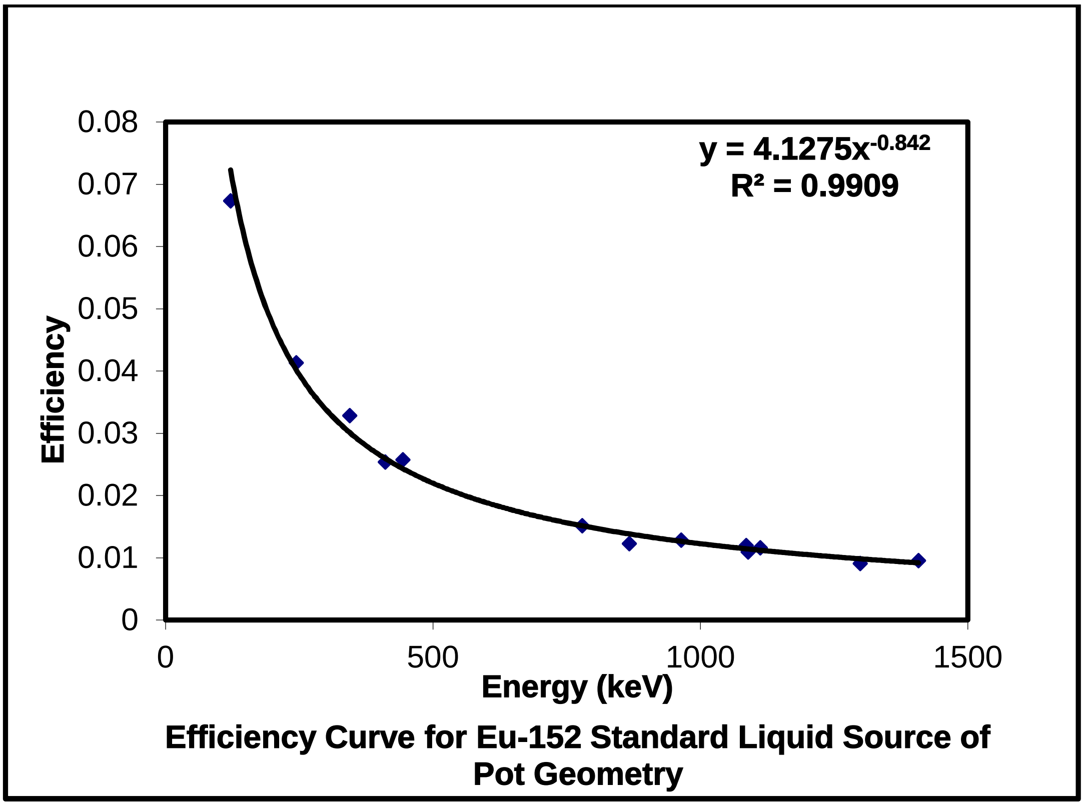

Fig 3.13(b): Efficiency curve for liquid matrix

3.10 Activity Concentrations of Soil, Sediment & Water Samples

The radionuclide contents and their activity levels of the each sample were measured using a calibrated HPGe detector of energy resolution of 2.0 KeV at 1.33 MeV of Cobalt-60 for a period of 10,000s. The activity concentrations (A) of each radionuclide in the sample was determined by using the count per second (cps) after subtracting the background counts from the gross counts for the same counting time under the selected photo peaks, weight of the sample, the photo-peak efficiency and the gamma intensity at a specific energy as (Usif and Taher, 2008):

$$A = \frac{cps}{E \times I \times W} \quad (3.19)$$

Where, A = Activity concentrations of the sample in $Bqkg^{-1}$ or BqL^{-1}.

Cps= Net counts per second= cps for the sample- cps for the background value

E = Counting efficiency of the gamma energy

I = Absolute intensity of the gamma ray and

W = Net weight of the sample (in kilogram or liter).

The errors in the measurements were expressed in terms of standard deviation (±σ), where σ is expressed as (Knoll, 1989)**:**

$$\pm = \left[\frac{N_s}{T_s^2} + \frac{N_b}{T_b^2} \right]^{1/2} \qquad (3.20)$$

Where, N_s is the sample counts measured in time T_s, and N_b is the background counts measured in time T_b. The standard deviation ±2σ in cps was converted into activity in Bqkg^{-1} according to equation (3.19).

3.11 Absorbed Dose Rate

The external outdoor absorbed gamma dose rates due to terrestrial gamma rays from the nuclides Ra-226, Th-232 and K-40 at 1m above the ground level has been calculated as (UNSCEAR, 2000)**:**

$$D\ (\mathrm{nGyh^{-1}}) = 0.462\ A_{Ra} + 0.604\ A_{Th} + 0.042\ A_{K} \qquad (3.21)$$

Where, A_{Ra}, A_{Th} and A_K are the specific activities of ^{226}Ra, ^{232}Th and ^{40}K respectively in BqKg^{-1}.

3.12 Outdoor Annual Effective Dose

The absorbed dose rate was converted into annual effective dose equivalent by using a conversion factor of 0.7 SvGy^{-1} recommended by the UNSCEAR 2000 and 0.2 for the outdoor occupancy factor by considering that the people on the average, spent 20% of their time in outdoors (Debertin and Helmer, 1988).The effective dose due to natural activity in the soil and sediment samples has been calculated by:

$$E\ (mSvyr^{-1}) = D \times 24 \times 365.25 \times 0.2 \times 0.7 \times 10^{-6} \qquad (3.22)$$

3.13 Radium Equivalent Activity

The radionuclide^{226}Ra, ^{232}Th and ^{40}Kare not homogeneously distributed in sediment and soil. The inhomogeneous distribution from naturally occurring radionuclide is due to disequilibrium between Ra-226 and its decay products. For uniformity in exposure estimates, the radionuclide concentrations are defined in terms of ‘Radium equivalent activity’ (Ra_{eq}) in Bqkg^{-1}. This allows comparison of the specific activity of materials containing different amounts of ^{226}Ra, ^{232}Th and ^{40}K according to Beretka and Mathew (Beretka and Mathew, 1985) as follows:

$Ra_{eq}\,(Bqkg^{-1}) = A_{Ra} + 1.43\,A_{Th} + 0.077\,A_K$(3.23)

Where, A_{Ra}, A_{Th} and A_K are the specific activities of ^{226}Ra, ^{232}Th and ^{40}K respectively in BqKg^{-1}.

3.14 External Hazard Index

The external hazard index (H_{ex}) is the indoor radiation dose rate due to the external exposure to gamma radiation in construction materials of dwelling which has been calculated by (Lu and Xiolan, 2006)

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (3.24)$$

Where, A_{Ra},, A_{Th} and A_K have the same meanings as in equation (3.21) and (3.23).

3.15 Radiometric Measurement

In the present work the measurement of the concentration of natural radioactivity (Ra, Th and K) in soil, sediment and water samples were performed by γ-ray spectrometric system, using high purity germanium (HPGe) detector having a relative efficiency of 20% and resolution (FWHM) 1.8 KeV at 1332 KeV γ-energy of ^{60}Co. The detector was connected to a multi-channel analyzer (MCA). Spectral data from the detector was accumulated on an MCA and analyzed using Genie-2000 software from Canberra. The detector was maintained in a vertical position with a lead cylindrical shield to avoid background radiation. All the samples were placed coaxially 10 cm from the surface of the detector and the counting time was 10,000 seconds.

The main contributors to radiological significance are the members of ^{238}U & ^{232}Th decay series and ^{40}K. Therefore, the emphasis was on the determination of natural activity of ^{226}Ra, ^{232}Th and ^{40}K. The content of ^{40}K was determined by measuring its single peak, 1460.88 KeV (10.7). Assuming secular equilibrium in the uranium and thorium decay series, the ^{226}Ra and ^{232}Th activities were determined indirectly via the activities of their daughter products. The choice of the reference nuclides was made so that the related peaks were sufficiently discriminated and intense. Based on such criteria, the nuclides chosen are shown in Table 3.7 for ^{226}Ra and ^{232}Th (Bruzzi *et al.*, 2000). The content of ^{226}Ra was measured using γ-energy of 295.18 KeV (18.15) ^{214}Pb, 351.92 KeV (35.10) ^{214}Pb, 609.35 KeV (44.60) ^{214}Bi, 1120.5KeV (14.70) ^{214}Bi and 1764.5 KeV (15.10). The contents of ^{232}Th was determined using 238.76 KeV (43.50) ^{212}Pb, 583.24 KeV (30.70) ^{208}Tl, 911.32 KeV (26.60) ^{228}Ac, 969.19 KeV (16.23) ^{228}Ac and 2613.2 KeV (35.60) ^{208}Tl. The background level was subtracted from each recorded spectrum.

Table 3.7: Gamma lines used for γ-spectrometry determinations

Principal radionuclide	Daughter product	Energy (KeV)	Intensity (yields)
^{226}Ra	^{214}Pb	295.18	0.1815
	^{214}Pb	351.92	0.351
	^{214}Bi	609.35	0.446
	^{214}Bi	1120.5	0.147
	^{214}Bi	1764.5	0.151
^{232}Th	^{214}Pb	238.76	0.435
	^{208}Tl	583.24	0.307
	^{228}Ac	911.32	0.266
	^{228}Ac	969.19	0.1623
	^{208}Tl	2613.2	0.356
^{40}K		1460.9	0.107

CHAPTER IV

Results and Discussion

From the gamma spectrometric analysis, the present study represents that three naturally occurring radionuclides were determined (^{226}Ra, ^{232}Th and ^{40}K) in the soil, sediment and water samples. Activity concentration of natural ^{226}Ra, ^{232}Th and ^{40}K, energy and efficiency calibration, lower limit of detection, radium equivalent activity, external hazard index, absorbed dose rate and outdoor annual effective dose in the samples were determined experimentally. An error analysis of the data has also been calculated. The results obtained in the present study have also been compared with other studies done at home and abroad. Activity concentration in soil, sediment, river water, river side tube-well water and village tube-well water samples, collected from Rupsha river bed and Rupsha area in Khulna district of Bangladesh has been measured using HPGe (High Purity Germanium) detector. Each of the samples has been counted for about 10000 sec. The activities have been expressed in BqKg^{-1} with counting error of two sigma (±2σ).

4.1 Radioactivity in soil samples

Activity concentration for ^{226}Ra, ^{232}Th and ^{40}K radionuclide in soil samples have been determined by equation (3.19) and the results for the same have been given in Table 4.1 & Table 4. 2 with the uncertainty level of ±2σ. The graphical presentations of the data have also been given in Fig 4.1, Fig 4.2 & Fig 4.3 respectively. The daughter radionuclide of^{226}Ra & ^{232}Th and their activity concentrations has been found in the soil samples collected from the Rupsha River area are given in Table 4.1. The activity concentrations of ^{214}Pb, ^{214}Bi, ^{212}Pb, ^{208}Ti and ^{228}Ac in these samples has been found to be varied from 46.11±3.92 BqKg^{-1} to 60.06±5.13 BqKg^{-1}, 39.19±12.38 BqKg^{-1} to 60.98±11.39 BqKg^{-1}, 66.04±3.1 BqKg^{-1} to 79.39±3.03 BqKg^{-1}, 54.74±6.81 BqKg^{-1} to 83.19±7.21 BqKg^{-1} and 64.12±11.1 BqKg^{-1} to 120.01±10.92 BqKg^{-1} respectively.

Table 4.1: Activity concentration of daughter radionuclides of soil samples

Sl no.	Sample ID	Location	Activity concentration ($BqKg^{-1}$)				
			^{214}Pb	^{214}Bi	^{212}Pb	^{208}Tl	^{228}Ac
1	S_1	Navy ghat	60.06±5.13	42.05±11.57	74.11±3.52	80.5±7.53	101.38±12.84
2	S_2	Dearha	51.13±4.57	52.46±11.6	69.46±3.29	76.37±7.07	95.54±12.01
3	S_3	Rajapur	46.11±3.92	45.45±4.54	69.42±2.96	61.15±5.75	64.12±11.1
4	S_4	Singer chor	52.78±4.44	60.98±11.39	67.04±3.1	67.29±6.42	77.57±10.66
5	S_5	Rahim-nagar	46.78±4.82	39.19±12.38	66.04±3.51	54.74±6.81	75.89±15.13
6	S_6	Ramnagar	58.41±4.77	43.82±4.99	77.14±3.39	83.19±7.21	88.77±13.73
7	S_7	Bagmara	55.61±4.52	40.35±10.19	69.38±3.14	72.47±6.6	68.13±10.21
8	S_8	Sigma	58.71±5.04	45.33±11.64	74.23±3.5	80.78±7.51	73.77±13.88
9	S_9	Rupsha bridge	58.4±4.75	49.43±10.97	78.26±3.4	68.99±6.62	98.61±11.83
10	S_10	Nimtala	52.97±3.99	43.13±8.84	79.39±3.03	83.08±6.28	120.01±10.92

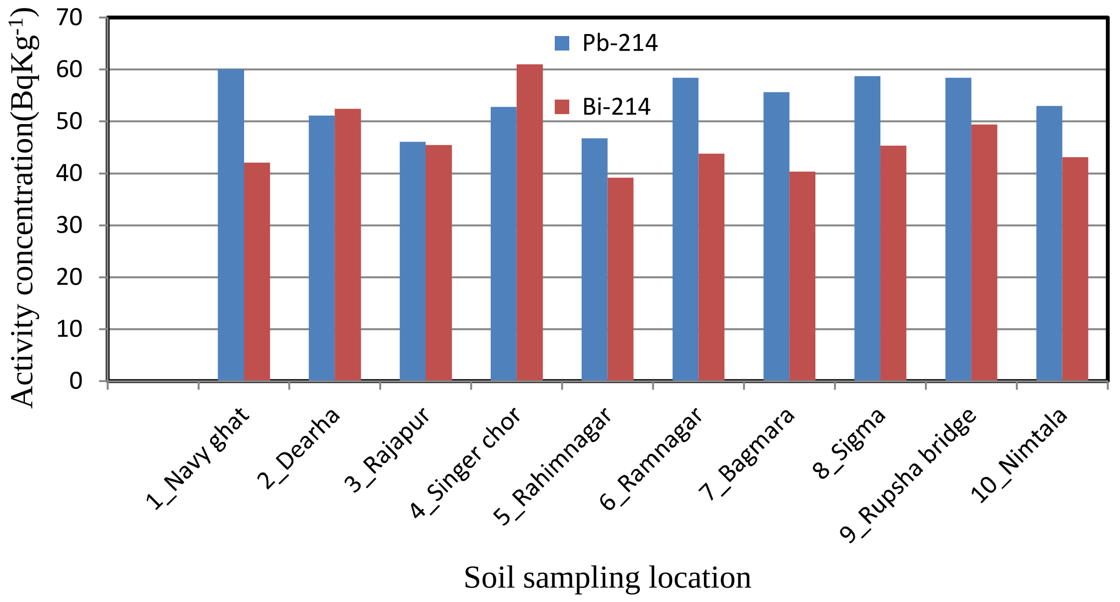

Fig 4.1: Bar diagram shows the activity concentrations of daughters (^{214}Pb, ^{214}Bi) of ^{226}Ra in soil samples collected from different location of Rupsha river side area, Khulna

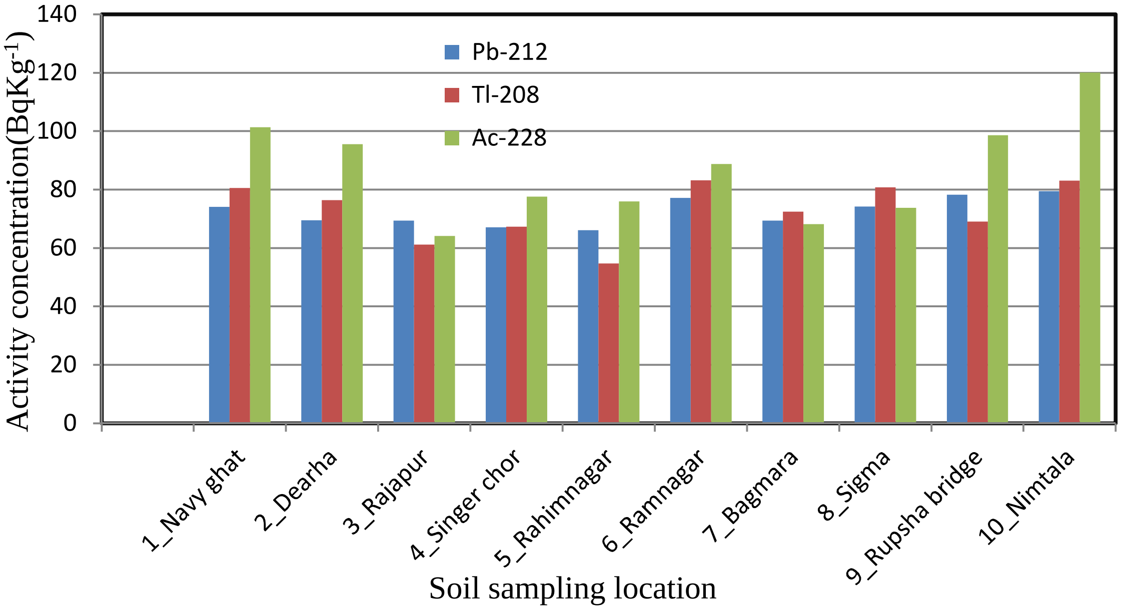

Fig 4.2: Bar diagram shows the activity concentrations of daughters(^{212}Pb,^{208}Tl, ^{228}Ac)of^{232}Th in soil samples collected from different location of Rupsha River side area, Khulna

Under the assumption that secular equilibrium was reached between ^{232}Th and ^{226}Ra with their decay products, the concentration of ^{226}Ra was determined from the average concentrations of ^{214}Pb (352Kev) and ^{214}Bi (609and1120 Kev) and that of ^{232}Th was determined from the average concentrations of ^{212}Pb (239 Kev), ^{208}Tl (583 Kev) and ^{228}Ac (911 and 969 Kev) in each sample under study. Since ^{40}K is directly γ-emitter, so its activity concentration could be determined from its single photo peak at 1460 Kev.

In soil samples, the activity concentrations of ^{226}Ra has been found in the range of 40.86±4.3 BqKg^{-1}to 53.92±7.86 BqKg^{-1}, with an average value of 50.16±7.2 BqKg^{-1}. This value was slight greater than the worldwide average value of 35 BqKg^{-1}. The activity concentrations of ^{232}Th have been found in the range of 64.9±6.6BqKg^{-1}to 94.16±6.74 BqKg^{-1}, with an average value of 77.23±7.43 BqKg^{-1}, this value was higher than that of the world average value of 30 BqKg^{-1}. And the activity concentrations of ^{40}K have been found in the range of 581.02±77.66 BqKg^{-1} to 1098.5±124.9 BqKg^{-1}, with an average value of 864.63±101.69 BqKg^{-1}. This value was significantly higher than that of worldwide average value of 400 BqKg^{-1}.

Table 4.2: Activity concentration & activity ratio of different radionuclides in soil samples

Sl no.	Sample ID	Location	Activity concentration (BqKg^{-1})			Activity ratio		
			^{226}Ra	^{232}Th	^{40}K	^{226}Ra/^{232}Th	^{226}Ra/^{40}K	^{232}Th/^{40}K
1	S_1	Navy ghat	51.06±8.35	85.33±7.96	904.39±111.59	0.60	0.06	0.09
2	S_2	Dearha	51.80±8.09	80.46±7.46	821.16±103.57	0.64	0.06	0.10
3	S_3	Rajapur	45.78±4.23	64.90±6.60	703.18±85.84	0.71	0.07	0.09
4	S_4	Singer chor	56.88±7.92	70.63±6.73	863.10±98.13	0.81	0.07	0.08
5	S_5	Rahimnagar	42.99±8.60	65.56±8.48	1098.50±124.90	0.66	0.04	0.06
6	S_6	Ramnagar	51.12±4.88	83.03±8.11	1030.69±105.25	0.62	0.05	0.08
7	S_7	Bagmara	47.98±7.36	69.99±6.65	777.43±95.93	0.69	0.06	0.09
8	S_8	Sigma	52.02±8.34	76.26±8.30	1013.98±113.11	0.68	0.05	0.08
9	S_9	Rupsha bridge	53.92±7.86	81.95±7.28	852.87±100.90	0.66	0.06	0.10
10	S_10	Nimtala	48.05±6.42	94.16±6.74	581.02±77.66	0.51	0.08	0.16
MIN			42.99±8.6	64.9±6.6	581.02±77.66	0.51	0.04	0.06
MAX			53.92±7.86	94.16±6.74	1098.5±124.9	0.81	0.08	0.16
AVG			50.16±7.2	77.23±7.43	864.63±101.69	0.656	0.0598	0.093
World AVG (UNSCEAR, 2000)			35	30	400	-	-	-

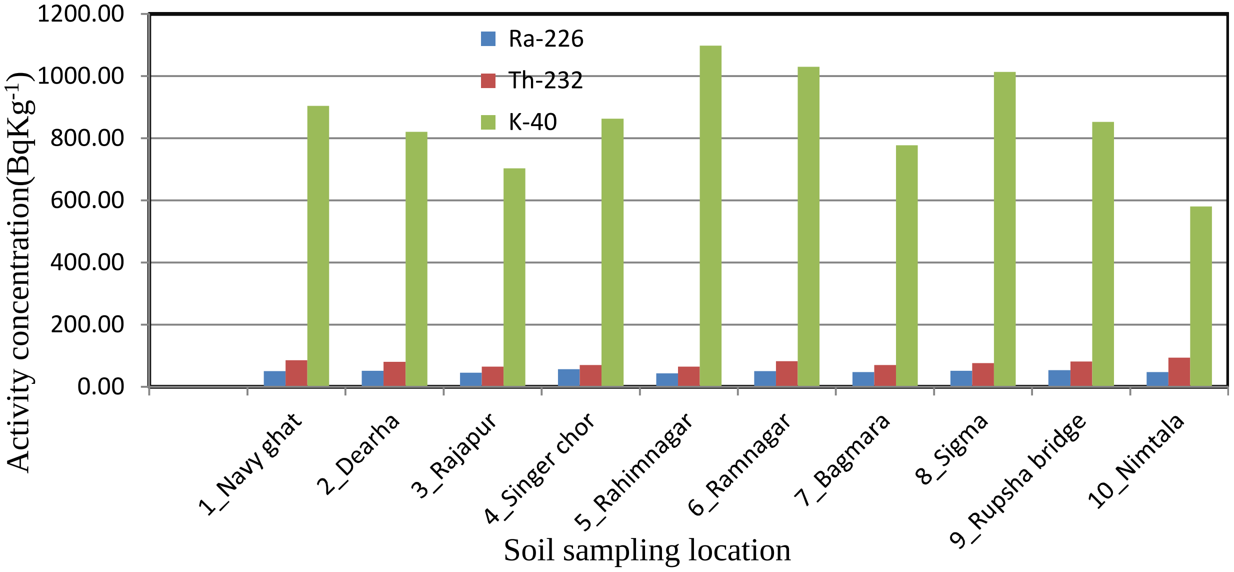

Fig 4.3: Bar diagram shows the activity concentration of ^{226}Ra, ^{232}Th & ^{40}K in Soil samples collected from different location of Rupsha river side area, Khulna

4.2 Radioactivity in sediment samples

Activity concentration for ^{226}Ra, ^{232}Th and ^{40}K radionuclide in sediment or sand samples has been determined by equation (3.19) and the results for the same are given in Table 4.3 & Table 4.4 with the uncertainty level of ±2σ. The graphical presentations are also given in Figure 4.4, Figure 4.5& Figure 4.6 respectively. The daughter radionuclides of ^{226}Ra & ^{232}Th and their activity concentrations have been found in the soil samples collected from the Rupsha River area are given in Table 4.3. The activity concentrations of ^{214}Pb, ^{214}Bi, ^{212}Pb, ^{208}Ti and ^{228}Ac in these samples has been found to be varied from 43.84±3.55 BqKg^{-1} to 58.58±4.93 BqKg^{-1}, 35.6±4.47 BqKg^{-1} to 59.19±5.66 BqKg^{-1}, 58.43±2.89 BqKg^{-1} to 80.27±3.56 BqKg^{-1}, 54.22±5.82 BqKg^{-1} to 83.93±7.45 BqKg^{-1} and 60.16 ±11.81 BqKg^{-1} to 94.68±14.02 BqKg^{-1} respectively.

Table 4.3: Activity concentration of daughter radionuclides of sediment or sand sample

Sl no.	Sample ID	Location	Activity concentration (BqKg^{-1})				
			^{214}Pb	^{214}Bi	^{212}Pb	^{208}Tl	^{228}Ac
1	SE_1	Navy ghat	52.99±4.68	48.03±11.49	73.56±3.41	83.93±7.45	78.14±13.73
2	SE_2	Dearha	52.17±4.66	42.55±11.11	80.27±3.56	77.91±7.22	78.75±13.72
3	SE_3	Rajapur	56.58±4.39	52.22±4.89	77.28±3.18	79.37±6.57	91.68±12.75
4	SE_4	Singer chor	57.34±4.8	59.19±5.66	73.93±3.39	71.35±6.88	89.59±14.14
5	SE_5	Rahimnagar	46.12±4.14	35.6±4.47	58.43±2.89	54.22±5.82	60.16±11.81
6	SE_6	Ramnagar	56.6±4.72	47.49±5.16	70.5±3.27	72.21±6.83	78.54±11.12
7	SE_7	Bagmara	58.58±4.93	53.2±5.55	79.74±3.56	64.45±6.7	79.08±13.85
8	SE_8	Sigma	53.8±4.59	45.86±10.91	75.52±3.36	72.45±6.78	94.68±14.02
9	SE_9	Rupsha bridge	53.88±4.58	50.09±11.16	73.73±3.3	62.26±6.33	73.34±12.8
10	SE_10	Nimtala	43.84±3.55	42.98±8.6	62.88±2.64	59.21±5.27	72.67±10.57

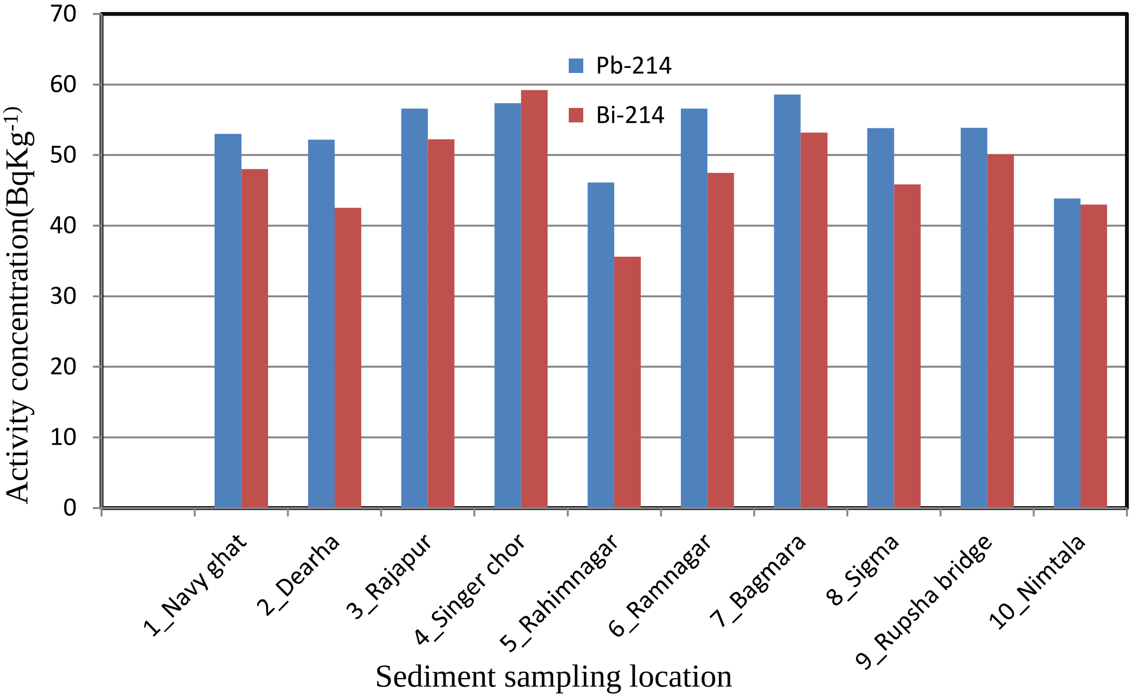

Fig 4.4: Bar diagram shows the activity concentrations of daughters (^{214}Pb, ^{214}Bi) of ^{226}Ra in sediment samples

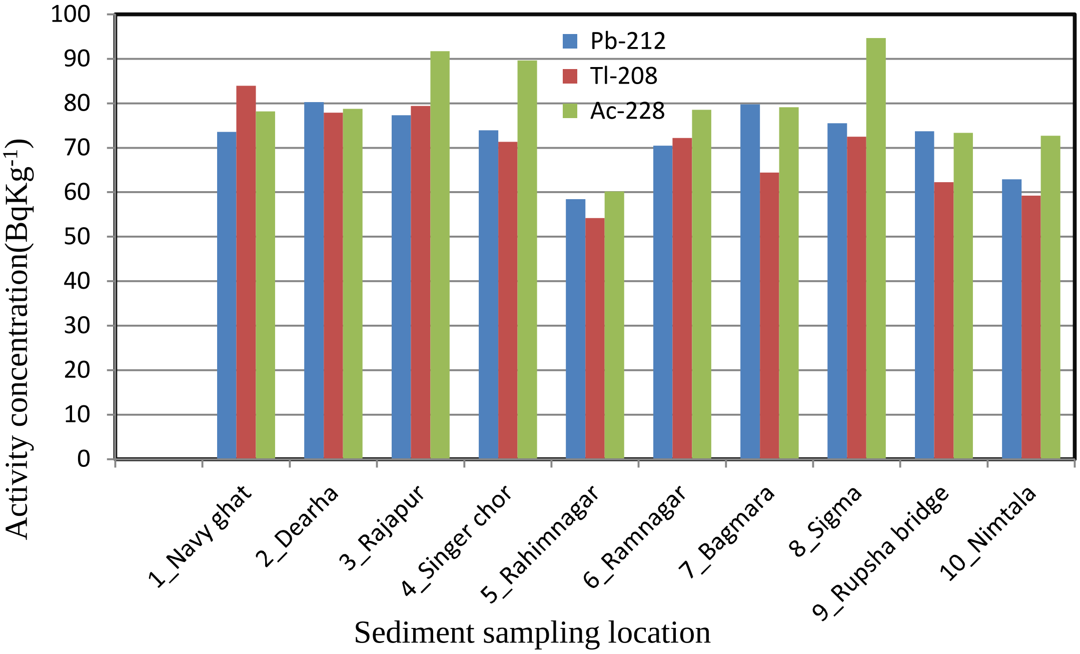

Fig 4.5: Bar diagram shows the activity concentrations of daughters (^{212}Pb, ^{208}Tl, ^{228}Ac) of ^{232}Th in sediment samples

In sediment samples, the activity concentrations of ^{226}Ra have been found in the range of 40.86±4.31 BqKg^{-1} to 58.27±5.23 BqKg^{-1}, with an average value of 58.27±5.23 BqKg^{-1}. This value was slight greater than the worldwide average value of 35 BqKg^{-1}. The activity concentrations of ^{232}Th have been found in the range of 57.6±6.84 BqKg^{-1} to 82.78±7.5

BqKg^{-1}, with an average value of 73.99±7.56 BqKg^{-1}, this value was higher than that of the world average value of 30 BqKg^{-1}. And the activity concentrations of ^{40}K have been in the range of 578.39±74.62 BqKg^{-1} to 1038.69±110.7 BqKg^{-1}, with an average value of 881.49±100.25 BqKg^{-1}. This value was significantly higher than that of worldwide average value of 400 BqKg^{-1}.

Table 4.4: Activity concentration & activity ratio of different radionuclides in sediment or sand samples

Sl no.	Sample ID	Location	Activity concentration (BqKg^{-1})			Activity ratio		
			^{226}Ra	^{232}Th	^{40}K	^{226}Ra/^{232}Th	^{226}Ra/^{40}K	^{232}Th/^{40}K
1	SE_1	Navy ghat	50.51±8.09	78.54±8.20	1007.81±109.35	0.64	0.05	0.08
2	SE_2	Dearha	47.36±7.89	78.98±8.17	861.80±106.34	0.60	0.05	0.09
3	SE_3	Rajapur	54.40±4.64	82.78±7.50	767.02±89.83	0.66	0.07	0.11
4	SE_4	Singer chor	58.27±5.23	78.29±8.14	988.34±107.24	0.74	0.06	0.08
5	SE_5	Rahimnagar	40.86±4.31	57.60±6.84	880.73±97.33	0.71	0.05	0.07
6	SE_6	Ramnagar	52.05±4.94	73.75±7.07	890.67±103.27	0.71	0.06	0.08
7	SE_7	Bagmara	55.89±5.24	74.42±8.04	1038.69±110.70	0.75	0.05	0.07
8	SE_8	Sigma	49.83±7.75	80.88±8.05	889.30±102.10	0.62	0.06	0.09
9	SE_9	Rupsha bridge	51.99±7.87	69.78±7.48	912.13±101.75	0.75	0.06	0.08
10	SE_10	Nimtala	43.41±6.08	64.92±6.16	578.39±74.62	0.67	0.08	0.11
MIN			40.86±4.31	57.6±6.84	578.39±74.62	0.60	0.05	0.07
MAX			58.27±5.23	82.78±7.5	1038.69±110.7	0.75	0.08	0.11
AVG			50.46±6.2	73.99±7.56	881.49±100.25	0.684	0.058	0.0856
World AVG (UNSCEAR, 2000)			35	30	400	-	-	-

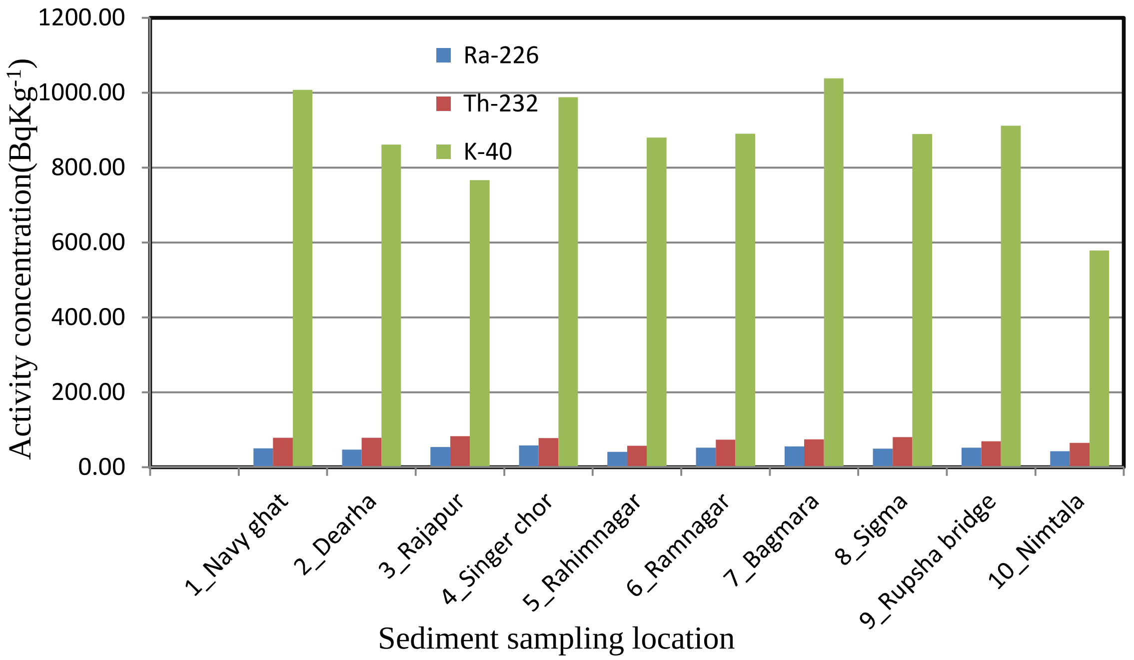

Fig 4.6: Bar diagram shows the activity concentrations of ^{226}Ra, ^{232}Th & ^{40}K in sediment samples

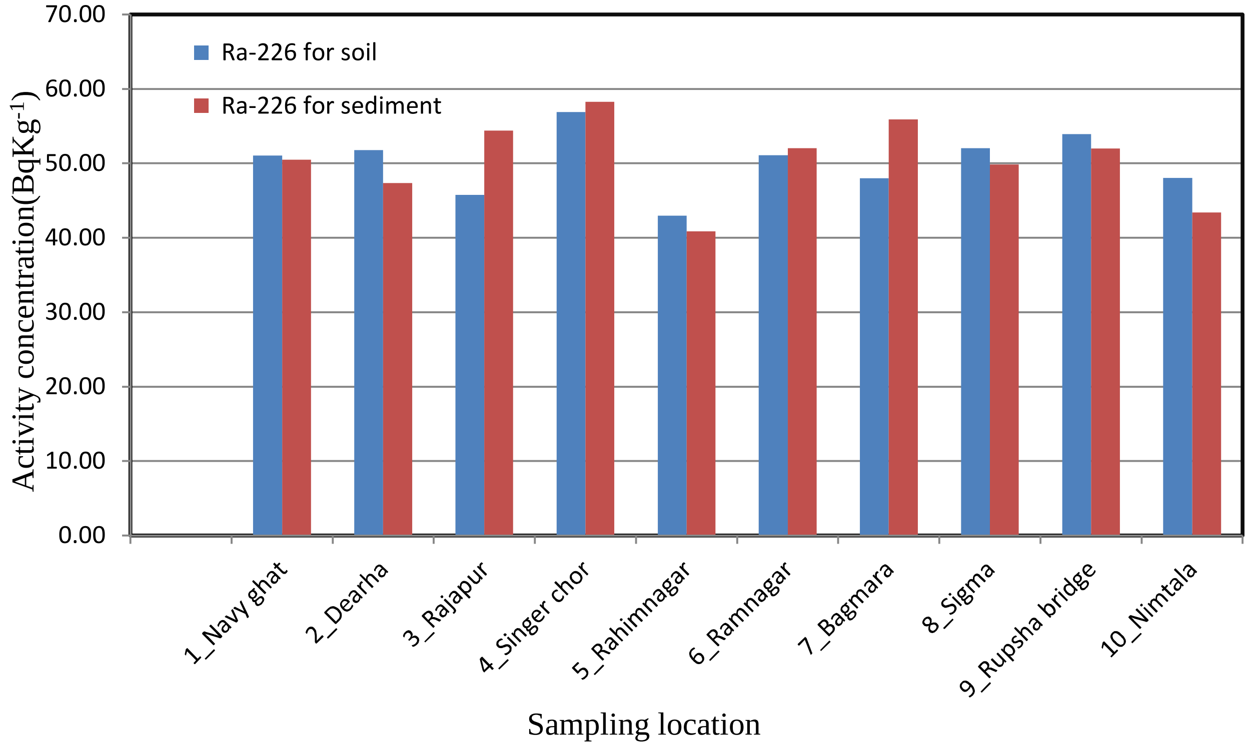

Fig 4.7: Bar diagram shows the activity concentrations of ^{226}Ra in soil & sediment

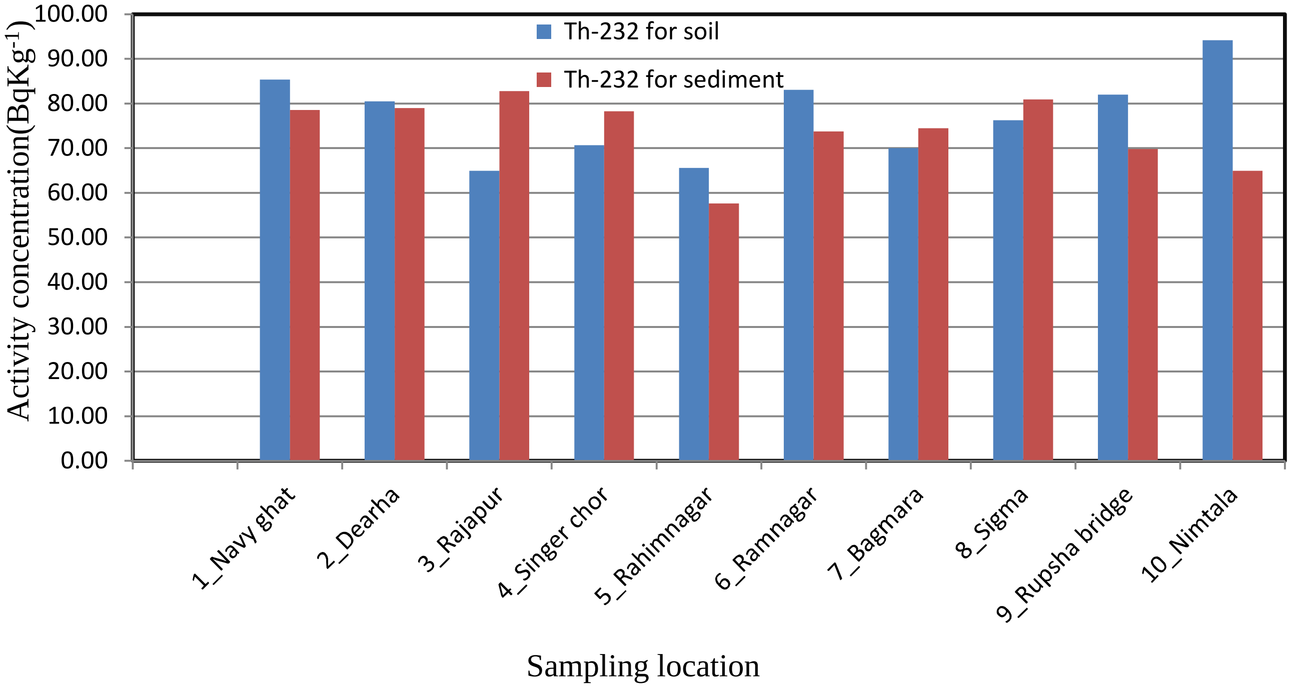

Fig 4.8: Bar diagram shows the activity concentrations of ^{232}Th in soil & sediment samples

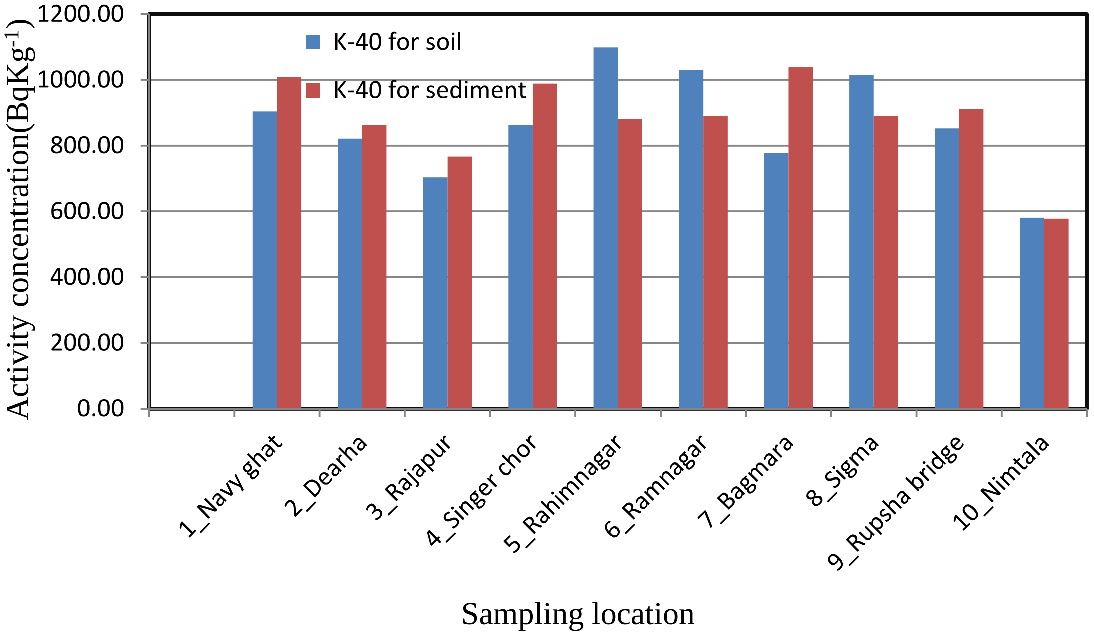

Fig 4.9: Bar diagram shows the activity concentrations of ^{40}K in soil & sediment samples

4.3 Radioactivity in water samples

In water samples, there are two kinds of water samples have been collected- surface water sample as Rupsha River water and drinking water sample as tube-well water.

4.3.1 Radioactivity in Rupsha River water samples

In surface water samples, the activity concentrations of ^{226}Ra and ^{232}Th has been found in the range of 1.26±0.98 BqL^{-1} to 5.51±2.5 BqL^{-1}, with an average value of 2.56±1.5 BqL^{-1} and 0.15±0.5 BqL^{-1} to 1.57±2.9 BqL^{-1} with an average value of 0.69±1.26 BqL^{-1} respectively. ^{40}K has been found in only one sample in the range of 109.65±32.17 BqL^{-1}. The results are given in Table 4.5 & Table 4.6 independently. Here BDL= Below Detection Limit.

Table 4.5: Activity concentration of daughter radionuclides of Rupsha River water samples

Sl no.	Sample ID	Location	Activity concentration (BqL^{-1})				
			^{214}Pb	^{214}Bi	^{212}Pb	^{208}Tl	^{228}Ac
1	1 RW	Navy ghat	1.26±.98	BDL	BDL	BDL	BDL
2	2 RW	Dearha	BDL	BDL	0.15±0.5	BDL	BDL
3	3 RW	Rajapur	5.18±1.29	2.09±1.42	0.54±0.52	BDL	0.35±2.77
4	4 RW	Singer chor	5.29±1.31	5.73±3.68	0.7±0.54	BDL	2.39±2.97
5	5 RW	Rahimnagar	1.92±1.07	1.12±3.35	BDL	BDL	BDL
6	6 RW	Ramnagar	1.9±1.03	BDL	0.9±0.55	0.03±1.24	BDL
7	7 RW	Bagmara	3.97±1.21	3.27±3.43	BDL	BDL	BDL
8	8 RW	Sigma	2.46±1.13	0.04±1.3	BDL	0.17±1.24	0.75±2.82
9	9 RW	Rupsha bridge	1.73±1.02	BDL	BDL	BDL	BDL
10	10 RW	Nimtala	1.37±0.99	BDL	BDL	BDL	1.57±2.9
MIN			BDL	BDL	BDL	BDL	BDL
MAX			5.29±1.29	5.73±3.68	0.7±0.54	0.17±1.24	2.39±2.97
AVG			2.79±1.11	2.45±2.64	0.57±0.53	0.1±1.24	1.27±2.87

Table 4.6: Activity concentration of different radionuclides in river water samples

Sl no.	Sample ID	Location	Activity concentration (BqL^{-1})		
			^{226}Ra	^{232}Th	^{40}K
1	1 RW	Navy ghat	1.26±0.98	BDL	BDL
2	2 RW	Dearha	BDL	0.15±0.50	BDL
3	3 RW	Rajapur	3.64±1.36	0.45±1.65	109.65±32.17
4	4 RW	Singer chor	5.51±2.50	0.70±0.54	BDL
5	5 RW	Rahimnagar	1.52±2.21	BDL	BDL
6	6 RW	Ramnagar	1.9±1.03	0.90±0.55	BDL
7	7 RW	Bagmara	3.62±2.32	BDL	BDL
8	8 RW	Sigma	2.46±1.13	0.38±1.41	BDL
9	9 RW	Rupsha bridge	1.73±1.02	BDL	BDL
10	10 RW	Nimtala	1.37±0.99	1.57±2.90	BDL
MIN			1.26±0.98	0.15±0.5	BDL
MAX			5.51±2.5	1.57±2.9	109.65±32.17
AVG			2.56±1.5	0.69±1.26	109.65±32.17

4.3.2 Radioactivity in tube-well water

In drinking water samples as tube-well water samples, the activity concentrations of ^{226}Ra and ^{232}Th have been found in the range of ‘Below Detection Level’ to 4.97±1.45 BqL^{-1} with an average value of 2.14±1.37 BqL^{-1} and ‘Below Detection Level’ to1.58 ±2.92 BqL^{-1} with an average value of 0.60±1.03 BqL^{-1}respectively. ^{40}K has been found in only one sample in the range of 6.7±30.34 BqL^{-1}. The results are given in Table 4.7 & Table 4.8 independently.

Table 4.7: Activity concentrations of daughter radionuclides in tube-well water samples

Sl no.	Sample ID	Location	Activity concentration (BqL^{-1})				
			^{214}Pb	^{214}Bi	^{212}Pb	^{208}Tl	^{228}Ac
1	1 TWR	Dearha	5.76±1.27	0.22±1.33	BDL	BDL	BDL
2	2 TWR	Rajapur Bazar	3.1±1.12	1.45±3.42	BDL	BDL	BDL
3	3 TWR	Rahimnagar	5.73±1.29	4.2±1.6	BDL	BDL	BDL
4	4 TWR	Bagmara	1.88±1.04	ND	BDL	BDL	1.58±2.92
5	5 TWR	Rupsha bridge	5.59±1.38	4.1±3.59	0.6±0.53	BDL	BDL
6	6 TWR	Nimtala	2.24±1.06	4.77±1.61	0.41±0.52	BDL	BDL
7	1_TWV	Rajapur village	BDL	BDL	0.6±0.53	BDL	0.15±2.83
8	2_TWV	Khan Mohammadpur	BDL	BDL	BDL	0.48±1.3	BDL
9	3_TWV	Aichgati	BDL	BDL	0.62±0.54	BDL	BDL
10	4_TWV	Joypur	0.77±0.95	BDL	BDL	BDL	BDL
11	5_TWV	Rupsha ghat	2.21±1.06	BDL	0.13±0.49	BDL	BDL
12	6_TWV	Elahipur	1.29±1.02	BDL	0.3±0.51	BDL	BDL
13	7_TWV	Noeihaty	1.55±1.06	BDL	BDL	BDL	5.24±3.16
14	8_TWV	Kharabad	1.73±1.08	BDL	0.6±0.53	BDL	BDL

Table 4.8: Activity concentration of different radionuclides in tube-well water samples

Sl no.	Sample ID	Location	Activity concentration (BqL^{-1})		
			Ra-226	Th-232	K-40
1	1 TWR	Dearha	2.99±1.30	BDL	BDL
2	2 TWR	Rajapur Bazar	2.28±2.27	BDL	BDL
3	3 TWR	Rahimnagar	4.97±1.45	BDL	BDL
4	4 TWR	Bagmara	1.88±1.04	1.58±2.92	BDL
5	5 TWR	Rupsha bridge	2.795±2.49	0.6±0.53	BDL
6	6 TWR	Nimtala	1.12±1.34	BDL	6.7±30.34
7	1_TWV	Rajapur village	BDL	0.38±1.68	BDL
8	2_TWV	Khan Mohammadpur	BDL	BDL	BDL
9	3_TWV	Aichgati	BDL	0.62±0.54	BDL
10	4_TWV	Joypur	0.77±0.95	BDL	BDL
11	5_TWV	Rupsha ghat	2.21±1.06	0.13±0.49	BDL
12	6_TWV	Elahipur	1.29±1.02	0.3±0.51	BDL
13	7_TWV	Noeihaty	1.55±1.06	BDL	BDL
14	8_TWV	Kharabad	1.73±1.08	0.6±0.53	BDL
MIN			BDL	BDL	BDL
MAX			4.97±1.45	1.58±2.92	6.7±30.34
AVG			2.14±1.37	0.60±1.03	6.7±30.34

These values have been found in water samples, much below than the worldwide average value. The rest of the radionuclides in almost all the water samples were below the detection limit. Therefore, the activity contents of the water samples collected from Rupsha River and Rupsha local area in Khulna city did not show any major evidence of radioactive enhancement.

Table 4.9: Absorbed dose rate,D ($nGyh^{-1}$), Outdoor annual effective dose,E($mSvyr^{-1}$), Radium equivalent activity (Ra_{eq}) and External hazard index(H_{ex}) of soil samples

Sl no.	Sample ID	Location	Radium equivalent activity, Ra_{eq}	External hazard index, H_{ex}	Absorbed dose rate, D($nGyh^{-1}$)	Outdoors annual effective dose, E ($mSvyr^{-1}$)
1	S_1	Navy ghat	242.52	0.66	113.11	0.14
2	S_2	Dearha	229.90	0.62	107.01	0.13
3	S_3	Rajapur	192.58	0.52	89.88	0.11
4	S_4	Singer chor	224.18	0.61	105.19	0.13
5	S_5	Rahimnagar	221.14	0.60	105.59	0.13
6	S_6	Ramnagar	249.02	0.67	117.06	0.14
7	S_7	Bagmara	207.77	0.56	97.09	0.12
8	S_8	Sigma	238.96	0.65	112.68	0.14
9	S_9	Rupsha bridge	236.60	0.64	110.23	0.14
10	S_10	Nimtala	227.26	0.61	103.47	0.13
MIN			192.58	0.52	89.88	0.11
MAX			249.02	0.67	117.06	0.14
AVG			226.99	0.61	106.13	0.13

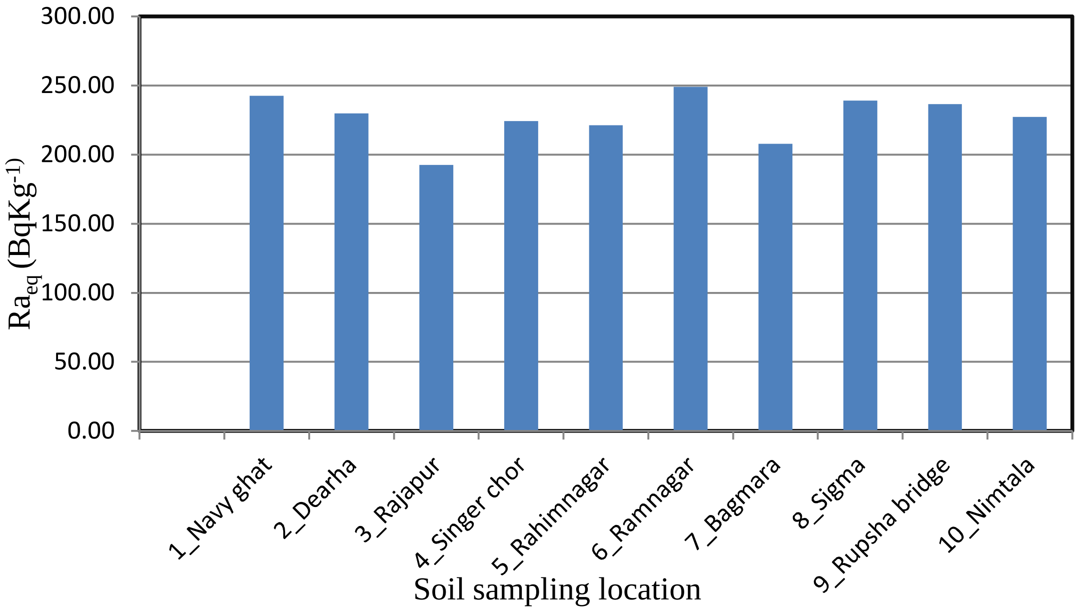

Fig 4.10: Bar diagram shows the Radium equivalent in soil samples

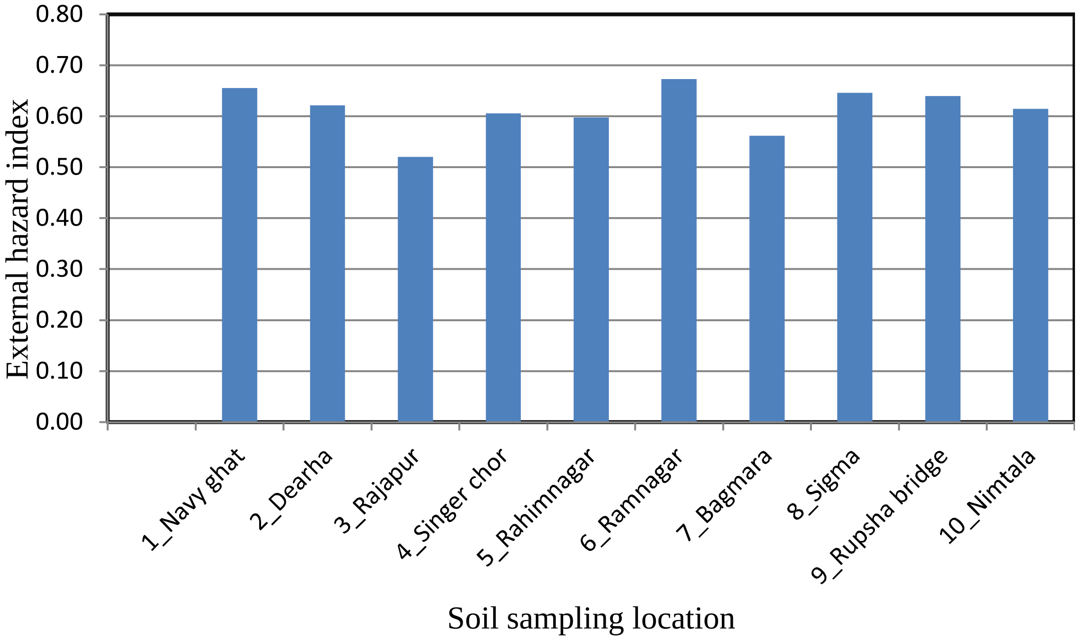

Fig 4.11: Bar diagram shows external hazard index (H_{ex}) in soil samples

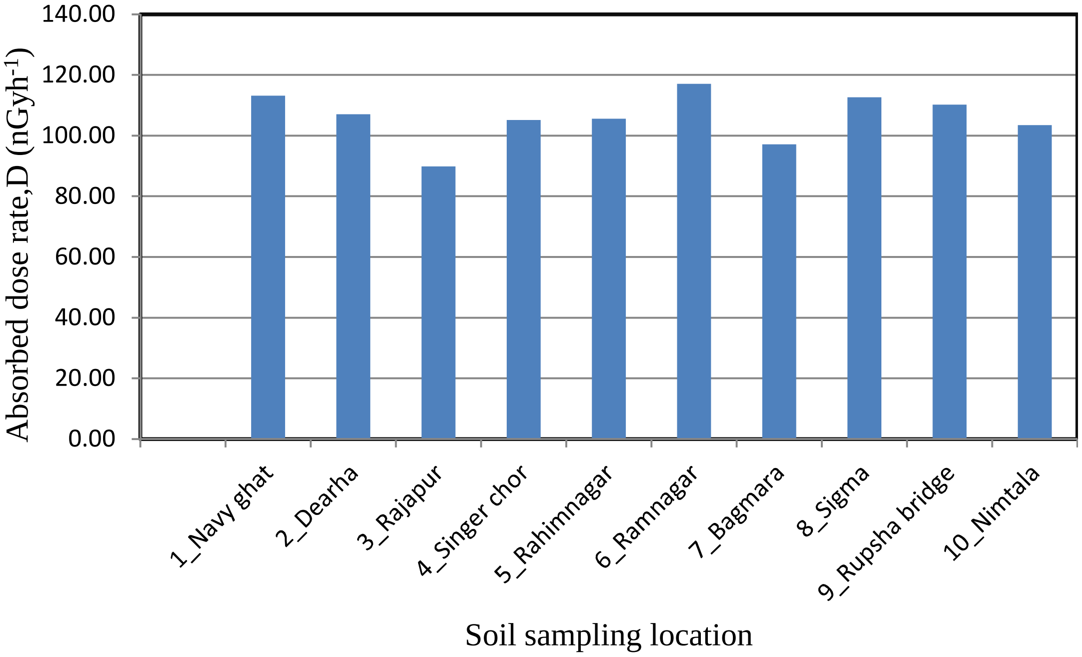

Fig 4.12: Bar diagram shows absorbed dose rate (ADR) in soil samples

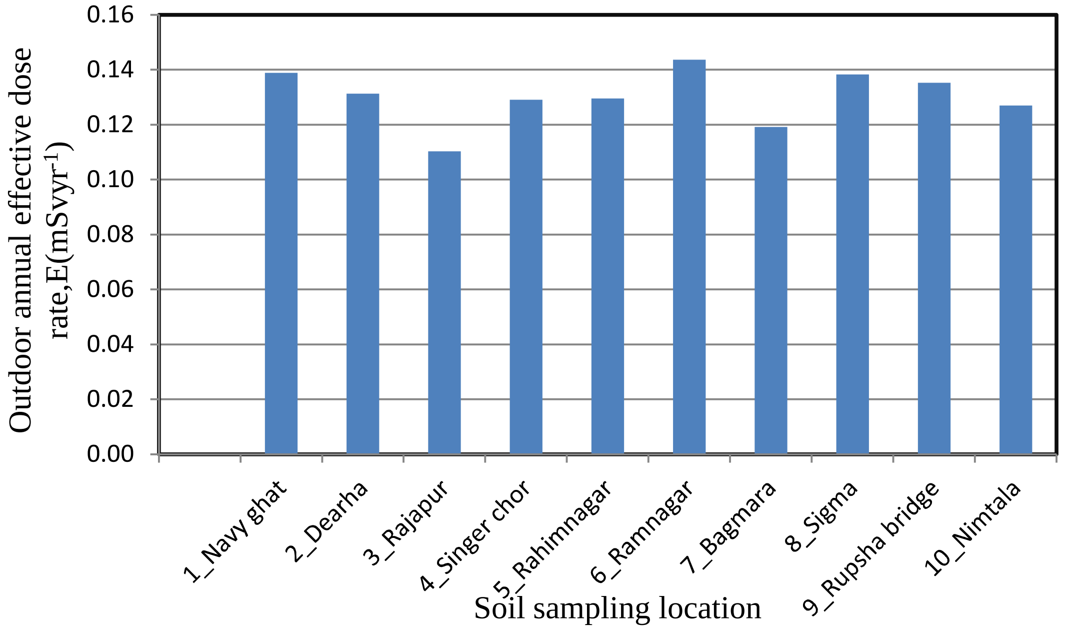

Fig 4.13: Bar diagram shows Outdoor annual effective dose rate in soil samples

Table 4.10: Absorbed dose rate, D (nGyh^{-1}) and Outdoor annual effective dose, E (mSvyr^{-1}), Radium equivalent activity (Ra$_{eq}$) and external hazard index (H$_{ex}$) of sediment samples

Sl no.	Sample ID	Location	Radium equivalent activity, Ra$_{eq}$	External hazard index, H$_{ex}$	Absorbed dose rate, D (nGyh^{-1})	Outdoors annual effective dose, E (mSvyr^{-1})
1	SE_1	Navy ghat	240.24	0.65	113.10	0.14
2	SE_2	Dearha	226.48	0.61	105.78	0.13
3	SE_3	Rajapur	231.65	0.63	107.34	0.13
4	SE_4	Singer chor	246.14	0.67	115.72	0.14
5	SE_5	Rahimnagar	190.90	0.52	90.66	0.11
6	SE_6	Ramnagar	225.92	0.61	106.00	0.13
7	SE_7	Bagmara	242.11	0.65	114.40	0.14
8	SE_8	Sigma	233.79	0.63	109.23	0.13
9	SE_9	Rupsha bridge	221.83	0.60	104.47	0.13
10	SE_10	Nimtala	180.64	0.49	83.56	0.10
MIN			180.64	0.49	83.56	0.1
MAX			246.14	0.67	115.72	0.14
AVG			223.97	0.61	105.03	0.13

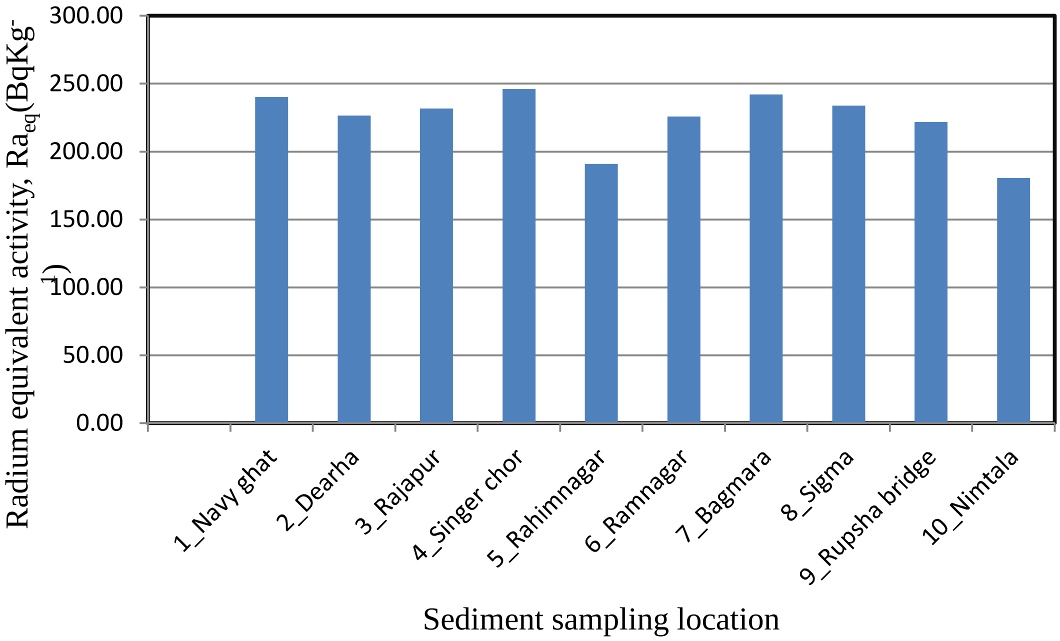

Fig 4.14: Bar diagram shows the Radium equivalent activity in sediment samples

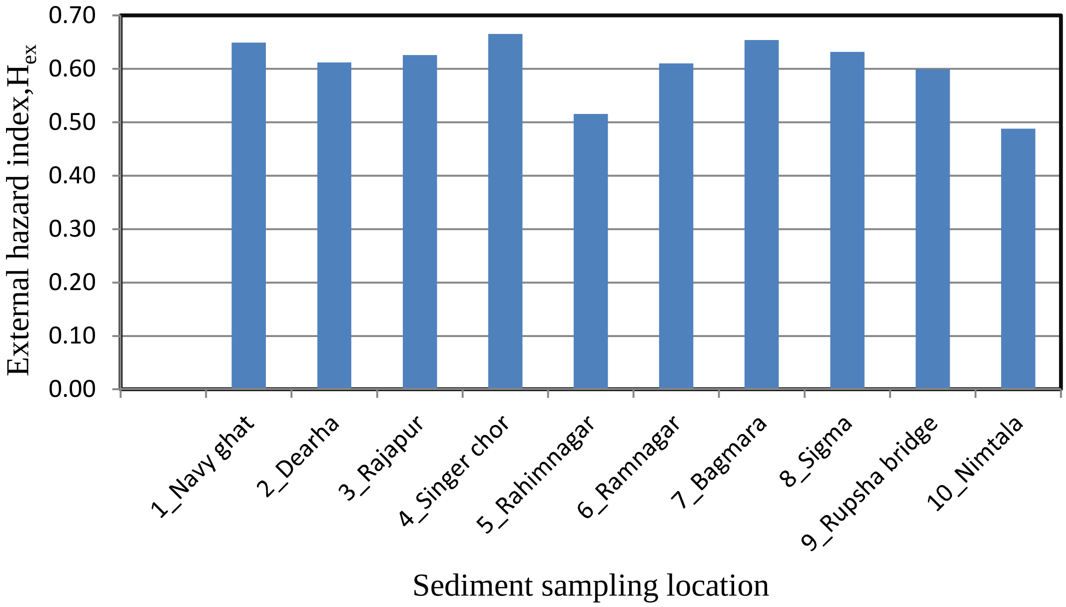

Fig 4.15: Bar diagram shows external hazard index (H_{ex}) in sediment samples

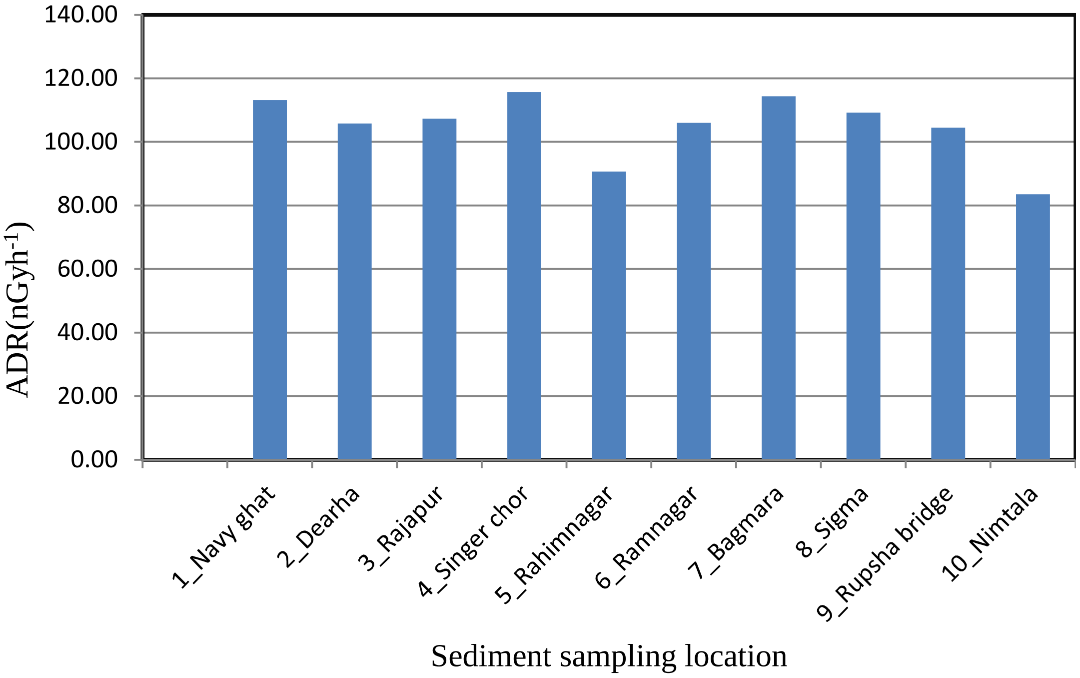

Fig 4.16: Bar diagram shows absorbed dose rate (ADR) in sediment samples

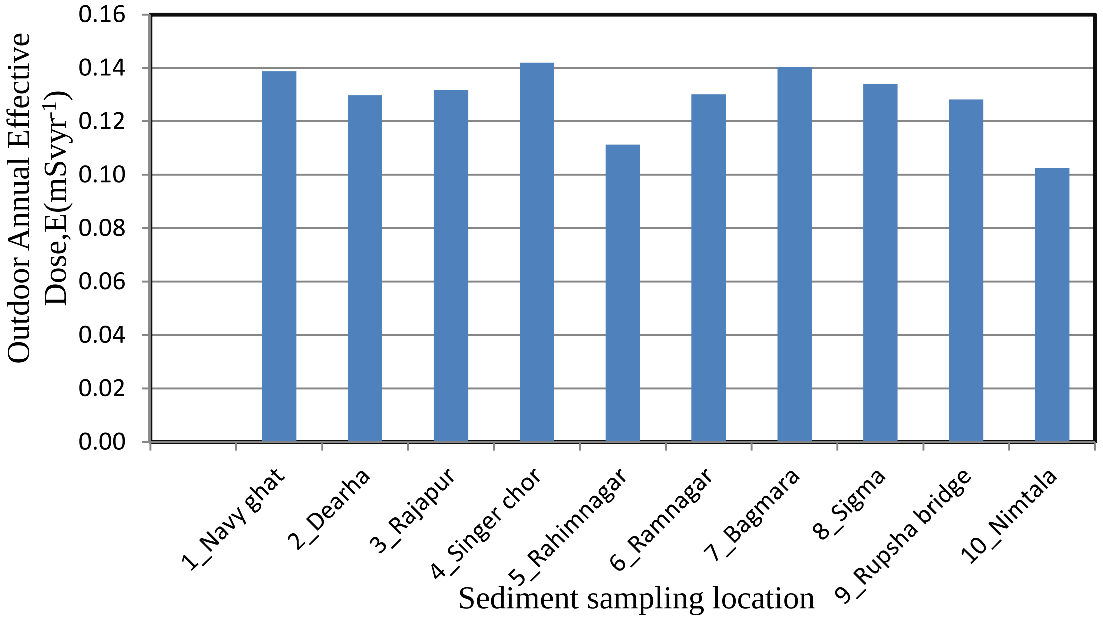

Fig 4.17: Bar diagram shows outdoor annual effective dose rate in Sediment samples

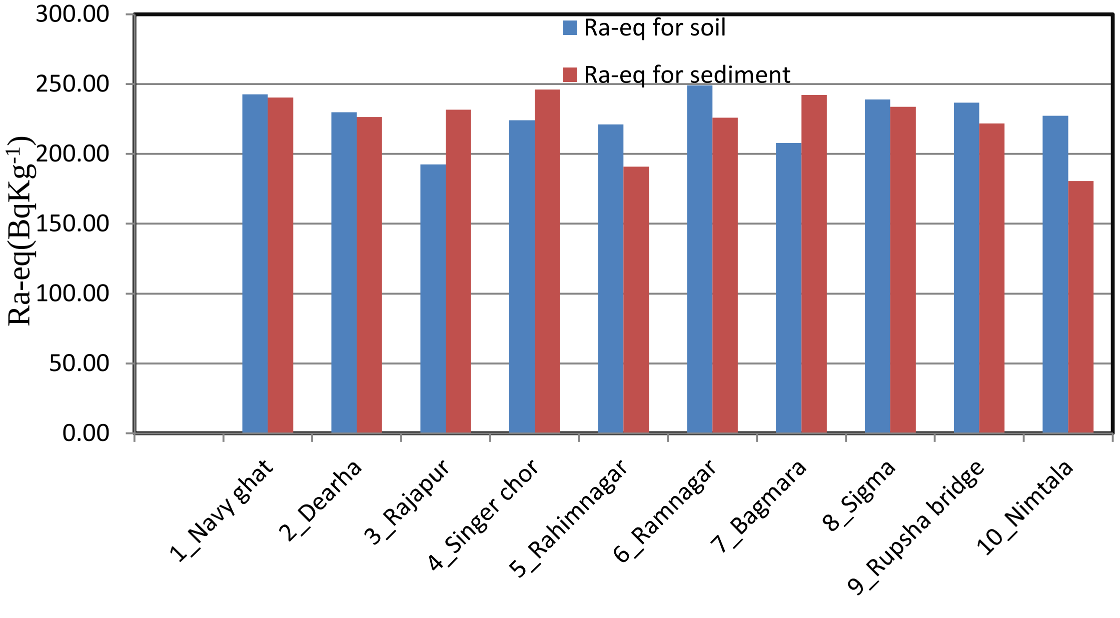

Fig 4.18: Bar diagram shows the Radium equivalent activity (Ra_{eq}) in soil & sediment

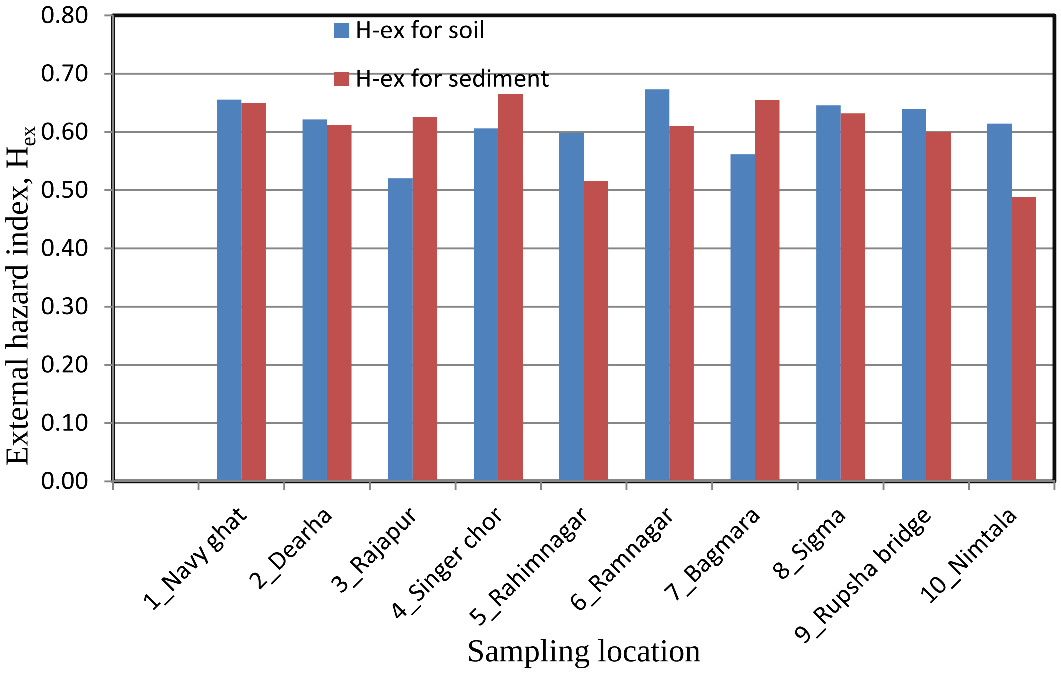

Fig4.19: Bar diagram shows the external hazard index (H_{ex}) in soil & sediment samples

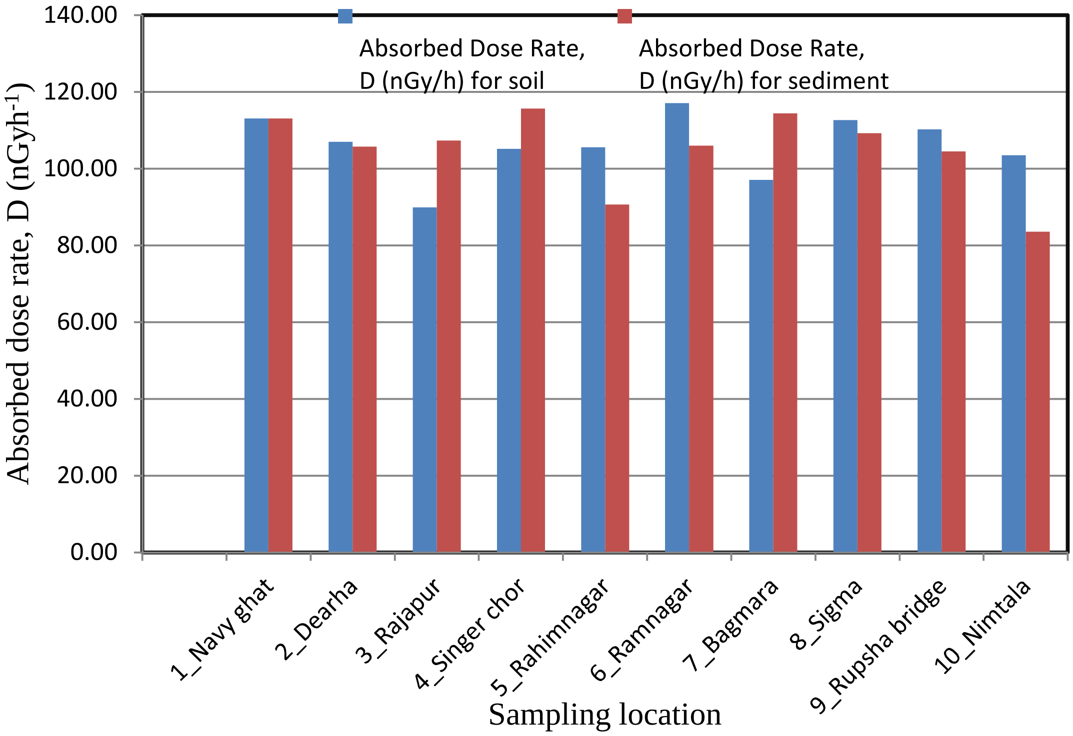

Fig 4.20: Bar diagram shows the absorbed dose rate in soil & sediment samples

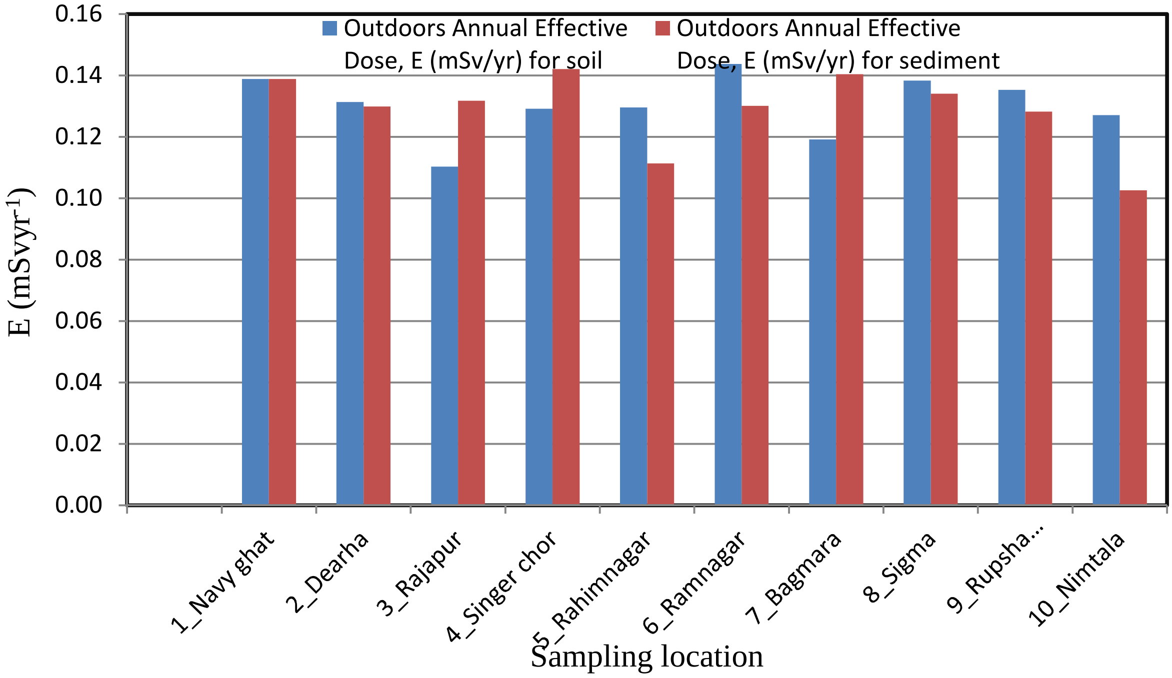

Fig 4.21: Bar diagram shows Outdoor annual effective dose in soil & sediment samples

Table 4.11: Absorbed dose rate, D (nGyh^{-1}) and External hazard index (H_{ex}) of River water samples

Sl no.	Sample ID	Location	External hazard index, (H_{ex})	Absorbed Dose Rate, D(nGyh^{-1})
1	1 RW	Navy ghat	0.003	0.58
2	2 RW	Dearha	0.0006	0.09
3	3 RW	Rajapur	0.034	6.55
4	4 RW	Singer chor	0.018	2.97
5	5 RW	Rahimnagar	0.004	0.7
6	6 RW	Ramnagar	0.009	1.42
7	7 RW	Bagmara	0.01	1.67
8	8 RW	Sigma	0.008	1.36
9	9 RW	Rupsha bridge	0.005	0.8
10	10 RW	Nimtala	0.01	1.58
Minimum			0.0006	0.09
Maximum			0.034	6.55
Average			0.01016	1.772

Table 4.12: Annual effective dose (mSv) of Ra-226, Th-232 & K-40 and Total dose (mSv) for adult of tube-well water samples

Sl no.	Sample ID	Location	Annual effective Dose (mSv)			Total dose (mSv)
			Ra-226	Th-232	K-40	
1	1 TWR	Dearha	0.61	BDL	BDL	0.61
2	2 TWR	Rajapur Bazar	0.47	BDL	BDL	0.47
3	3 TWR	Rahimnagar	1.02	BDL	BDL	1.02
4	4 TWR	Bagmara	0.38	0.27	BDL	0.65
5	5 TWR	Rupsha bridge	0.57	0.10	BDL	0.67
6	6 TWR	Nimtala	0.23	BDL	0.03	0.26
7	1_TWV	Rajapur village	BDL	0.06	BDL	0.06
8	2_TWV	Khan Mohammadpur	BDL	BDL	BDL	BDL
9	3_TWV	Aichgati	BDL	0.10	BDL	0.10
10	4_TWV	Joypur	0.16	ND	BDL	0.16
11	5_TWV	Rupsha ghat	0.45	0.02	BDL	0.47
12	6_TWV	Elahipur	0.26	0.05	BDL	0.31
13	7_TWV	Noeihaty	0.32	BDL	BDL	0.32
14	8_TWV	Kharabad	0.35	0.10	BDL	0.46
MIN			BDL	BDL	BDL	BDL
MAX			1.02	0.27	0.03	1.02
AVG			0.44	0.1	0.03	0.43

4.4 Radiological Indices

In order to assess the health effects, the radiation hazards such as absorbed dose rate (D), outdoor annual effective dose (E), Radium equivalent activity (Ra_{eq}) and external hazard index (H_{ex}) have been calculated from the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K and the values are given in Table 4.9 and Table 4.10.

From Table 4.9 & 4.10 it is seen that absorbed dose rate is 89.88 to 117.06 nGyh^{-1}with an average 106.13 nGyh^{-1} for soil samples, for sediment samples it is 83.56 to 115.72 nGyh^{-1} with an average value of 105.03 nGyh^{-1} and this value is higher than the world average 57 nGyh^{-1}. The outdoor annual effective dose is 0.11to 0.14 mSvyr^{-1} with an average value of

0.13 $mSvyr^{-1}$ for soil sample, for sediment sample it is 0.10 to 0.14 with an average value of 0.13 which is less than the world average value of 0.480 $mSvyr^{-1}$.

The mean value of Radium equivalent activity is 226.99 $BqKg^{-1}$ for soil samples and 223.97 $BqKg^{-1}$ for sediment samples. The Radium equivalent activity falls below the world average value of 370 $BqKg^{-1}$ (UNSCEAR, 2000). It is apparent that the Radium equivalent activity originating from different regions shows some variations, which are likely to be related to the position of collected soil samples, sediment samples, water samples, transport process etc. This is important in selecting suitable soils, sediment, water and rice not only for construction but also for agriculture purposes in order to keep the radiation hazard minimum.

The mean value of external radiation hazard index was 0.61 for soil samples and 0.61 for sediment samples which was far less than the unity indicating the non-hazardous category of the samples. The values of hazard indices confirmed that it was safe for human to live and work at that area and there were yet no significant radiological impact on the environment revealed from this study. The values found from the current study were compared with those of other published data in home and abroad and also assured that the radioactivity level was within the safety limit yet.

CHAPTER V

Conclusions

The detection of radionuclides and estimation of their activity concentration, radiological impact in the collected soil, sediment and water samples have been done by gamma spectrometry technique which is the most reliable and well-established method for radioactivity analysis. The measurement showed that only naturally occurring radionuclides were present in the collected samples. The activity concentration of ^{137}Cs which is the only man-made radionuclide was below the minimum detectable limit. This implies that the samples studied were free from artificial radionuclide. The natural radioactivity concentrations of ^{226}Ra, ^{232}Th for the soil and sediment samples are slightly higher than the worldwide average values but for ^{40}K, it is significantly higher than the worldwide average value. The activity concentrations of water samples do not show any major evidence of radioactive contamination. The values of mean absorbed dose rates are higher than worldwide average value of 55 nGyh^{-1} and annual effective dose are approximately same to the world wide average value of 0.115 mSvyr^{-1}(UNSCEAR, 2000) for soil and sediment samples. Whereas, the mean values of radium equivalent activity and external hazard index determined in soil and sediment samples of the area under the study are lower than the corresponding permissible limits (370 Bq.Kg^{-1}and 1). The current results are also compared to the other parts of the country and abroad. However, these values of doses are much below the permissible level set by ICRP, and, therefore, there is no immediate health risk on workers and public due to natural or artificial radioactivity present in the samples of present study. Therefore, the area under present study may be termed as radiologically safe. Nevertheless, elevated level of health risk may be caused due to natural terrestrial radiation from these environmental elements on the inhabitants of this area if the uncontrolled industrial process and agricultural activities continue. This study also provides current exposure level and base-line database for the development of future guidelines in the country or in a neighbouring country.

Future Plan

In further studies, more samples from each sampling area need to be collected in order to obtain more accurate data. Due to time limitations, the determination of activity concentration for each sample was measured only one time. Ideally, the measurements should to be repeated in order to obtain good statistical precision. Further studies need to be carried out in order to allow comparison with areas in which there is no utilization of fertilizers or no industrial activities like brick fields. Future work also need to be carried out into all over Bangladesh. Since the gamma spectroscopy results using one sample from each location indicate that radioactivity levels of the samples under study are slightly higher than the world average value, it is recommended that further studies with large representation of samples should be conducted. For the development of future guidelines in the country a more enriched and informative base-line database should be planned and the current study providing current exposure level will hopefully have a good contribution on it.

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